# EXHIBIT 4

# Expert Rebuttal Report of

# David Sabatini, PhD, PE, BCEE

**January 14, 2025**

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## SECTION 1: BACKGROUND AND EXPERIENCE:

I am David Ross Boyd Professor Emeritus of civil engineering and environmental science at the University of Oklahoma (OU). I joined OU in 1989, became Associate Director of the Institute for Applied Surfactant Research in 2000, and was Founding Director of the OU WaTER Center in 2005. I was appointed the Sun Oil Company Endowed Chair in 2002, and I held this position until my retirement in 2022. I received my BS in Civil Engineering (CE) from the University of Illinois in 1981, my MS CE from Memphis State University in 1985, and my PhD from Iowa State University in 1989. In addition to my PhD, I am a registered Professional Engineer (PE) and am a Board Certified Environmental Engineer (BCEE).

Over the past four decades, my research has focused on advancing and utilizing fundamental physical-chemical concepts for drinking water treatment and groundwater remediation. As an indication of my expertise and reputation on these topics, I served as Editorial Board member of the *Journal of Water, Sanitation and Hygiene for Development* and Editor-in-Chief of the *Journal of Contaminant Hydrology*, and I have coauthored or coedited five books and over 200 refereed journal publications on these topics. For over three decades, I have taught a graduate-level course on the physical-chemical process for drinking water treatment. Further details on these and other items, including any publications I have authored in the last ten years, are in my full vitae, attached to this report as Exhibit B.

The impact of my research is demonstrated by its being cited 13,728 times with an h-index of 67 (67 of my articles have been cited more than 67 times), an i-100 index of 34 (34 of my articles have been cited more than 100 times), and an i-10 index of 202 (Google Scholar Citations: December 30, 2024). My research funding totals $12.8 M, including funding from the National Science Foundation, Environmental Protection Agency, Department of Energy, and Department of Defense.

As a further indication of the impact of my work, my awards include the following (a partial list): Life Member of the American Water Works Association (AWWA, 2022), Oklahoma Higher Education Hall of Fame – Oklahoma Higher Education Heritage Society (2020), International Service Award from U.S. National Chapter of International Association of Hydrogeologists (2017), Distinguished Alumnus Award from the University of Illinois Civil and Environmental Engineering (2012), DaVinci Fellow Award – DaVinci Institute of Oklahoma (2010), the Oklahoma Medal for Excellence from the Oklahoma Foundation for Excellence (2010), the Japanese Oil Chemist Society Lectureship Award (2006), and the National Groundwater Association Groundwater Remediation Project Award (2006). From 1997 to 1998, I was honored to be a Senior Fulbright Scholar at the Universitaet Tuebingen, Germany.

My background and experience sufficiently and uniquely qualify me to comment on the fate of contaminants in Camp Lejeune water treatment plants and distribution systems, as well as the ultimate delivery of contaminated drinking water to marines and their family members.

## SECTION 2: INTRODUCTION

The Bell Legal Group retained me in April 2023 on behalf of the *Camp Lejeune Water Litigation* Plaintiffs. Relevant to my expert rebuttal, my expertise is in physicochemical processes impacting drinking water treatment and water quality. I am being compensated at $300 per hour for preparing this report. My rate for deposition and trial testimony is $400 per hour. I have not testified by deposition or trial in the last four years.

My methodology for assessing Dr. Hennet's Expert Report Opinions 2, 10 and 13 was to evaluate the basis of his opinions relative to losses of VOCs during water treatment, storage, and filling of water buffaloes, study the supporting documents that Hennet relies upon along with the AH Environmental Report (2004), perform calculations to help identify reasons for the disparity in estimated losses between the two studies, evaluate appropriateness of input parameters to Hennet's calculations, and assess limitations of the approaches utilized to estimate VOC losses. Based on these analyses and my professional experience and judgment, I suggest modifications to Hennet's calculations that, in my opinion, more accurately capture the losses experienced in water treatment and storage at Camp Lejeune.

My expert opinion is based on my education and experience as a civil engineer and environmental scientist and on the available data and information, which, in addition to ATSDR reports, include government documents, standard textbooks, and refereed scientific journal articles documenting scientifically accepted contaminant losses in water treatment and delivery (see Exhibit A for a list of these documents). A complete list of all materials I have considered in rendering the opinions in this rebuttal will be produced within seven days of my report's submission.

## SECTION 3: BRIEF DESCRIPTION OF HADNOT POINT AND TARAWA TERRACE WATER TREATMENT PLANTS AND BACKGROUND ON VOLATILIZATION CONCEPTS PERTINENT TO MY EXPERT REBUTTAL REPORT

### 3.1 HADNOT POINT AND TARAWA TERRACE WATER TREATMENT PLANTS

AH Environmental (2004) and Hennet (2024) provide detailed descriptions of the Hadnot Point and Tarawa Terrace water treatment plants, which I briefly summarize below. Additional details can be found in the AH Environmental and Hennet reports. I do not address the Holcomb Boulevard water treatment plant as VOCs did not adversely impact its raw water (Maslia et al., 2013).

Figure 3-1 (AH Environmental, 2004) summarizes the Hadnot Point water treatment plant, showing the raw water reservoir, the five parallel Spiractor softening units, the recarbonation basin, the five parallel gravity filters, and the finished water reservoirs. The system was designed to process the flow of 5 MGD (million gallons per day). Not shown in Figure 3-1 is the 300,000-gallon water tower filled from the finished water reservoir. See AH Environmental (2004) (Exhibit D) and Hennet (2024) for additional details on the treatment system.

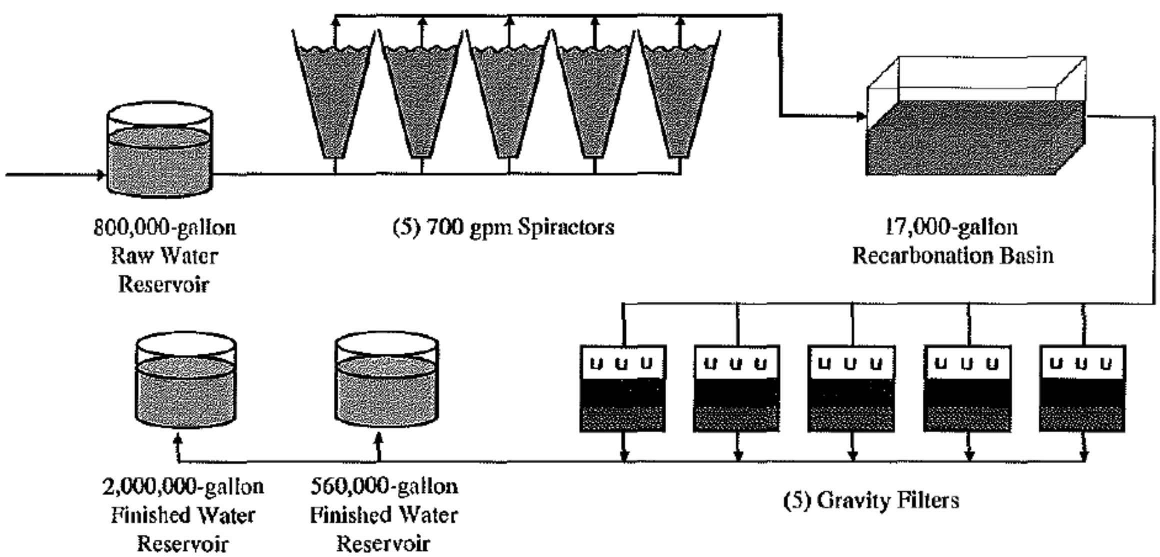



Figure 3-1 Hadnot Point Water Treatment Plant (Figure 2-3, p. 2-8, AH Environmental, 2004)

Figure 3-2 (AH Environmental, 2004) summarizes the Tarawa Terrace water treatment plant showing the Spiractor softening unit, the six parallel pressure filters, and the finished water reservoir. The system was designed to process 1 MGD of flow. Not shown in the diagram is the 250,000-gallon water tower filled from the finished water reservoir. See AH Environmental (2004) and Hennet (2024) for additional details on the treatment system.

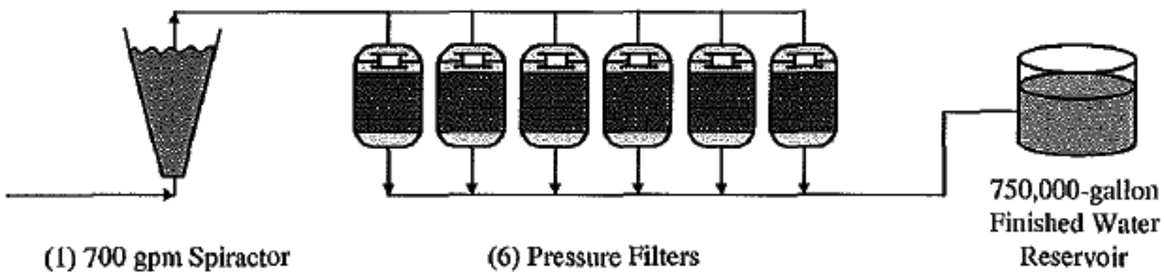



Figure 3-2 Tarawa Terrace Water Treatment Plant (Figure 2-6, p. 2-11, AH Environmental, 2004)

### 3.2 BACKGROUND REGARDING VOLATILIZATION LOSSES

The primary potential losses of interest in the Hadnot Point and Tarawa Terrace water treatment processes result from contaminant volatilization from the water into the air. In the Camp Lejeune case, the contaminants of concern (COCs) are the volatile organic compounds (VOCs) tetrachloroethylene (PCE), trichloroethylene (TCE), 1,2-trans-dichloroethylene (1,2-tDCE), vinyl chloride (VC) and benzene (Bz).

Equilibrium volatilization is described by Henry's Law (Schwarzenbach et al., 1993; AWWA, 1990; Crittenden et al., 2012), which indicates that the gaseous (air) concentration of a compound ($C_{air}$) is linearly proportional to the liquid (water) concentration of that compound ($C_{water}$), as shown in Equation 3-1. The proportionality constant (H) in Henry's Law (Equation 3-1) is known as Henry's Law Constant. Rearranging Equation 3-1 to Equation 3-2, Henry's constant is a compound's partitioning ratio (relative air to water concentration) at equilibrium.

$$C_{air} = H * C_{water} \qquad \text{(Equation 3-1)}$$

$$H = C_{air} / C_{water} \qquad \text{(Equation 3-2)}$$

An analogy illustrating Henry's law is the carbonation of Coca-Cola (Coke). In a Coke bottle, the $CO_2$ in the Coke (carbonation) is in equilibrium with the $CO_2$ in the air between the Coke and the lid (the headspace); this partitioning follows Henry's Law. If you remove the lid, you hear the pressurized $CO_2$ in the headspace escape the bottle. If you drink half of the Coke and put the lid back on, the $CO_2$ in the remaining Coke will eventually equilibrate with the new headspace, leading to loss of $CO_2$ from the Coke. This reduces the carbonation of the Coke and, in the vernacular, the Coke goes flat.

Henry's Law assumes there is sufficient time for equilibrium partitioning to be achieved. Following up on the Coke analogy, after you consume half the Coke and replace the lid, it takes

time for the Coke $CO_2$ to come into equilibrium with the new headspace (air). If you measured the $CO_2$ in the air over time, you would find that it gradually increases towards the equilibrium value predicted by Henry's Law. Thus, in early time periods, the air concentration and volatilization would be much less than predicted by Henry's Law. This time-dependent (kinetic) process is a function of the driving force for volatilization (the concentration gradient between equilibrium and actual air concentration of the VOC), the area across which volatilizations is occurring, and the resistance to contaminant leaving the liquid and going into the gas phase. This process is analogous to heat flow; in the winter, heat is lost from the home in proportion to the temperature difference from inside to outside, the home's surface area, and the heat flow resistance (degree of insulation).

For volatilization, the kinetic process is described by a two-film mass transfer process (AWWA, 1990; Crittenden et al., 2012), as summarized in Equation 3-3. In this equation, J is the contaminant transfer rate (from liquid to gas in our case), $K_L$ is the inverse resistance to contaminant flow (diffusion-controlled transfer from the water to the air), A is the area over which contaminant transfer occurs, and delta C is the concentration gradient between aqueous concentration and equilibrium gaseous concentration (the driving force). As delta C approaches zero (as we approach equilibrium), contaminant flow from liquid to air (volatilization) decreases until equilibrium is reached.

$$J = K_L \, A \, (\text{delta C}) \qquad \text{(Equation 3-3)}$$

To summarize, Henry's Law indicates the maximum volatilization that can be experienced given sufficient time to reach equilibrium (Equation 3-1). For shorter time periods, the air concentration (volatilization) may be much less than predicted by Henry's Law, depending on how quickly VOCs can migrate from the water to the air phase. In the early stages of contaminant volatilization, the air concentration and associated volatilization losses will be controlled by the area for contaminant transfer, diffusion-controlled transfer from water to air, and the driving force (difference between actual and equilibrium gaseous concentrations) as captured by the two-film transfer processes (Equation 3-3).

## SECTION 4: SUMMARY OF MY OPINIONS IN RESPONSE TO HENNET'S OPINIONS 2, 10 AND 13

Based on my review and analysis of the documents discussed in this report and listed in Exhibit A, my education and experience, and my review of the scientific literature, I have reached the following opinions within reasonable scientific and engineering certainty, all of which are explained in further detail in Section 5 of this report:

4.1 Hennet (2024) overestimated VOC losses in the raw water during storage, treatment, and distribution; only minor VOC losses occurred in these systems (in response to Hennet's Opinion 2 suggesting *substantial* losses - Hennet, 2024, p. 3-1).

- *The water treatment processes at Camp Lejeune would cause only minor losses of the VOCs of interest. Assumptions in Hennet's calculations led to the overestimation of these losses. Rather than 15 to 32% losses by Hennet's calculations, I estimate < 6 to 12% losses for the range of VOCs.*

4.2 The ATSDR models indirectly accounted for VOC losses during water treatment, storage, and distribution (in response to Hennet's Opinion 10, suggesting losses not accounted for - Hennet, 2024, p. 3-3)

- *Water samples from the distribution system and homes were included in the final stage of calibration.*

4.3 Hennet (2024) overestimated VOC losses in the mobile field water tanks (water buffaloes); water concentrations in the water buffaloes were only moderately lower than in the water treatment plants' treated water. (In response to Hennet's Opinion 13, suggesting they were *substantially* lower - Hennet, 2024, p. 3-3).

- *While losses during tank filling were possible, assumptions in Hennet's calculations led to overestimates of these losses. While Hennet estimated on the order of 41% to 61% losses, I estimate no more than 15% to 22% losses for filling through filler pipe/strainer and 4.2% to 6.7% for filling through the manhole for the range of VOCs.*

I reserve the right to amend these opinions should new information be provided or become available to me.

## SECTION 5: DISCUSSION OF OPINIONS

This section provides a detailed discussion substantiating the three opinions summarized in Section 4. Evidence to support my opinions is provided by referring to standard textbooks and peer-reviewed journal articles as documented in my discussion.

### 5.1 HENNET (2024) OVERESTIMATED VOC LOSSES IN THE RAW WATER DURING STORAGE, TREATMENT, AND DISTRIBUTION; ONLY MINOR VOC LOSSES OCCURRED IN THESE SYSTEMS. (IN RESPONSE TO HENNET'S OPINION 2, WHICH SUGGESTS SUBSTANTIAL LOSSES).

Hennet (2024) and AH Environmental (2004) each estimated VOC losses in various stages of the water treatment, storage, and distribution system, as summarized in Hennet's Exhibit 2-1 (reproduced below as Figure 5-1). This schematic represents both the Tarawa Terrace and Hadnot Point treatment systems with the variation that Tarawa Terrace did not have a raw water storage tank and Hadnot Point included a recarbonation basin between the Spiractors and the filters (see Section 3.1 for a brief summary and AH Environmental, 2004, Section 2.3 for a detailed description of the water treatment plants). The Holcomb Boulevard water treatment plant is not addressed as VOCs did not adversely impact its raw water (Maslia et al., 2013).

The main points of potential VOC losses estimated by Hennet (2024) and AH Environmental (2004) are in the treatment process (specifically the Spiractors), the raw water storage (Hadnot Point only), and the treated storage (clearwell) tanks, and the water towers. Since the Spiractor design volumes and flow rates were the same for all Spiractors in both treatment systems, the VOC loss estimate approach applies to Tarawa Terrace and Hadnot Point as discussed in the next section. Since raw water storage, clearwell, and water tower VOC losses are estimated similarly but vary by tank size and flow rate, they will be discussed in the subsequent section. I will present the VOC loss estimates from Hennet (2024) and AH Environmental (2004) along with my own conclusions based on my calculations and assessments.

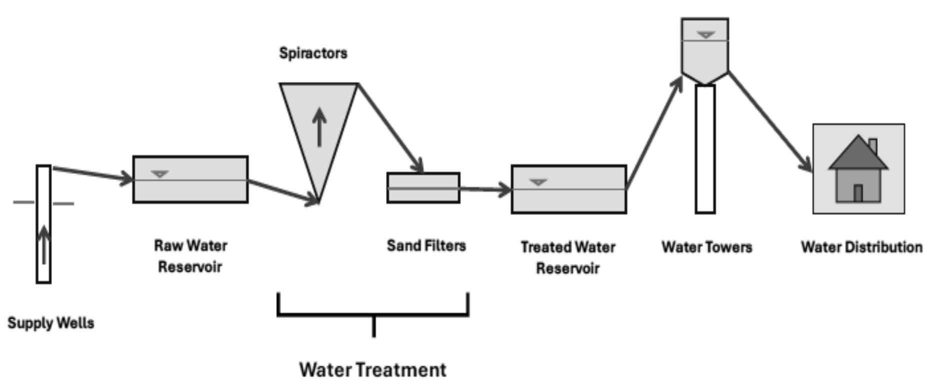



**Exhibit 2-1. Flow Through Schematic for Water from Supply Wells to Distribution**

Figure 5.1 Flow Schematic for Water Treatment and Distribution (Hennet, 2024, p. 5-2)

### 5.1.1 SPIRACTORS

AH Environmental (2004) and Hennet (2024) followed the same approach for estimating VOC losses in the Spiractors, with their results summarized in Table 5.1.

Table 5.1 – Spiractor PCE and TCE volatilization losses estimated by AH Environmental (AH 2004), Hennet (2024), and corrected for AH Environmental

| Source | TCE Loss (%) | PCE Loss (%) |
|---|---|---|
| AH Environmental (2004)* | 6.1 | 7.7 |
| Hennet (2024)** | 10.0 | 12.2 |
| AH Environmental (2004) – corrected*** | 5.2 | 6.2 |

*AH (2004), Sec 4.2, p. 4-1

**Hennet (2024), Exhibit 2-4, p. 5-6

***Exhibit C.1

To understand why Hennet estimated VOC losses larger than AH Environmental, I reviewed the estimation approach they used (both followed the method outlined in Nakasone (1987), summarized in AH (2004), and incorporated into WATER9 (EPA, 1994)). Upon repeating their calculations I identified two reasons for the differences in the estimated VOC losses: (1) AH Environmental transposed an exponent in their Equation 11 (AH 2004 – Exhibit D, p. 3-4) – the last term should be $h^{0.31}$ instead of $h^{0.13}$ (Nakasone, 1987), Hennet caught this error as well; and, (2) AH Environmental used a water drop in the effluent pipe of 1 ft (0.3 m) while Hennet used a fall height of 2 ft (0.6 m) (leading to fall height Z values of 0.375 m and 0.675 m, respectively).

Relative to the transposed exponent, I recalculated AH Environmental's losses using the correct exponent and listed the updated values in Table 5.1 as corrected. Implementing the correct form of the equation reduced the volatilization loss values predicted by AH (Table 5.1), thus not accounting for Hennet's higher loss values. Rather, Hennet's use of 2 ft as the water drop in the effluent pipe is the reason for his higher VOC loss estimates.

So why did Hennet choose to use 2 ft instead of AH Environmental's value of 1 ft? In Exhibit 2-3a (p. 5-5, Hennet, 2024), Hennet shows a picture of a Spiractor effluent pipe that was being replaced, although he doesn't indicate which water treatment plant this came from. In this figure, Hennet indicates a 2 ft drop from the top of the effluent pipe to the top of the pipe, carrying water away from the effluent pipe. I surmise that this is why Hennet chose to use a 2 ft (0.6 m) value. However, AH Environmental (2004) indicates that the water drop was no greater than 1 ft for Hadnot Point (AH, 2004, p. 4-2), while for Holcomb Boulevard, which did not have a recarbonation basin, the water drop could approach 2 ft. AH Environmental indicates that the recarbonation basin created a headloss (constricted the flow) such that water backed up in the Spiractor effluent pipe resulting in a 1 ft versus 2 ft water drop in the Spiractor effluent pipe for Hadnot Point. This impact can be seen visually in AH Environmental (2004) Figure 4-1 (Exhibit D – p. 4-2) for Hadnot Point and AH Environmental (2004) Figure 4-3 (Exhibit

D – p. 4-3) for Holcomb Boulevard; Figure 4-3 shows more free fall versus Figure 4-1 for Hadnot Point, justifying AH Environmental's choice of the 1 ft (0.3 m) water drop in the Spiractor effluent pipe. Hennet (2024) does not refer to AH Environmental's discussion regarding the impact of the Hadnot Point recarbonation basin on the water drop in the Spiractor effluent pipe. Further, AH Environmental's Figure 3-4 (Exhibit D – p. 3-10), which Hennet includes as his Exhibit 2-2 (Hennet, 2024, p. 5-4), shows a 12 in drop. I thus conclude that AH Environmental's use of 1 ft (0.3 m) for the water drop in the Spiractor effluent pipe is justified.

In Table 5.2, I extend AH Environmental's corrected calculations for a 1 ft (0.3 m) drop to 1,2-tDCE, VC (vinyl chloride), and Benzene (Bz) and summarize Hennet's values for a 2 ft drop for all five VOCs. In all cases, Hennet's values are almost twice that compared to AH Environmental's use of 1 ft. In my opinion, as discussed above, the AH values are more appropriate.

Table 5.2 – Spiractor VOC Loss Estimates for AH Environmental Water Drop in Effluent Pipe (1 ft), vs. Hennet (2 ft)

| Source | TCE (%) | PCE (%) | 1,2-tDCE (%) | VC (%) | Bz (%) |
|---|---|---|---|---|---|
| AH Environmental (1 ft)* | 5.2 | 6.2 | 5.9 | 9.9 | 4.3 |
| Hennet (2024) (2 ft)** | 10.0 | 12.2 | 11.1 | 19.1 | 8.1 |

* Exhibit C.1

** Hennet (2024), Exhibit 2-4, p. 5-6

One final observation can be made regarding calculated VOC losses in the Spiractor effluent pipe. The Nakasone (1987) method estimates VOC losses due to water flow over a weir. A weir is a vertical barrier or wall over which water flows, cascading as a free fall onto the other side of the barrier or wall. The water flows over the barrier in a parallel path above and below the weir. In reality, the water exits the Spiractor over the circular edges of a pipe (see AH (2004) Figures 3-2 and 3-3, Exhibit D, pp. 3-8 and 3-9, respectively), so that the water flow after the "weir" is no longer parallel but converges in the center (see AH (2004) Figure 4-1, Exhibit D, p. 4-2). As the water (flow lines) converge in the center, the area for volatilization decreases. Thus, while I am not aware of a better approach than Nakasone (1987) for making this estimate, in my opinion, the estimated values of VOC losses will be conservative (higher than actually experienced). All this to say, I find this to be further justification supporting the corrected AH Environmental Spiractor volatilization losses in Table 5.2 for Hadnot Point and Tarawa Terrace. If anything, in my opinion, the actual values were lower than AH Environmental predicted rather than higher as Hennet (2024) suggests.

#### *5.1.2 Storage Tanks (Raw Water, Treated Water/Clearwells, Water Towers)*

Both AH Environmental (2004) and Hennet (2024) followed the approach outlined in Thomas (1990) for estimating VOC losses in raw water and treated water (clearwell) tanks, and water towers. Whereas AH Environmental (2004) estimated VOC losses of **0.04% or less** (AH, 2004, p. 4-4) for the tanks, Hennet estimated loss values summed across these tanks of **6 to 14%** for the range of VOCs (Hennet, 2004, Exhibits 2-4 and 2-5, pp. 5-6 to 5-10). To understand

why VOC losses from Hennet were greater than AH Environmental's values, I reviewed the estimation approach as summarized in AH Environmental (2004) and referred back to the original Thomas (1990) document. Thomas (1990) compiles four different methods for estimating volatile losses from water bodies open to the atmosphere: (1) Mackay and Wolkoff, (2) Lisa and Slater, (3) Chiou and Freed, and (4) Smith et al. AH Environmental (2004) and Hennet (2024) followed the Smith et al. (1980) approach as outlined in Thomas (1990). I agree with this choice.

Given that they both followed the Smith et al. approach, why did their estimates differ so dramatically? Upon looking further into their respective calculations, AH Environmental (2004) invoked the Southworth (not Southgate as referred to by Hennet, 2024, p. 5-11, footnote 64) method for estimating volatilization rates for input to the Smith et al. approach (AH Environmental used Thomas, 1990, Equations (15-32) to (15-34) in their analysis which are AH's Equations 4 to 6, p. 3-12 to 3-13, 2004 – see Exhibit D). The Southworth technique was developed for moderately volatile compounds ($10^{-5}$ < Henry's Constant < $10^{-3}$ atm-m$^3$/mol), while VOCs of concern to Camp Lejeune are highly volatile (> $10^{-3}$ atm-m$^3$/mol; see Thomas, 1990, Table 15-4, pp. 15-24 to 15-25). As such, the Southworth approach does not apply for VOCs of interest to Camp Lejeune which all have Henry's Constants > $10^{-3}$ atm-m$^3$/mol. Hennet (2024) correctly uses the more generalizable approach outlined in Thomas (1990), which is appropriate for VOCs of interest at Hadnot Point and Tarawa Terrace water treatment plants. This difference explains why Hennet's (2024) estimates are different, and higher, than AH Environmental. Nonetheless, in my opinion, there is much room for improvement in Hennet's calculations, and cause to assess the applicability of the Thomas approach to Camp Lejeune's raw water, clearwell, and water tower tanks.

The approaches outlined in Thomas (1990) are for systems open to the atmosphere (*e.g.*, a pond, lake, or river). In contrast, the Camp Lejeune water treatment tanks, from raw water to clearwell to water towers, are covered – they are not open to the atmosphere. A Coke bottle, with and without a lid, can demonstrate the contrast between a closed (covered) system and an open system. Relative to the Coke bottle, the carbonation in the Coke is analogous to VOCs in Camp Lejeune water. As the carbonation ($CO_2$) comes out of the water (Coke), it will volatilize into the atmosphere if the bottle is uncovered, causing the Coke to "go flat" or lose its carbonation. If the Coke bottle is covered (has a lid), the $CO_2$ leaving the Coke will come into equilibrium with the $CO_2$ in the air above the Coke. As more $CO_2$ accumulates in the air above the Coke, this slows down the rate of volatilization until $CO_2$ in the air and Coke come into equilibrium via Henry's Law (Henry's Constant is the ratio of the gaseous versus liquid concentration of a compound at equilibrium), at which point no more $CO_2$ leaves the Coke (see Section 3.2 for further discussion of these concepts). This simple analogy will help us understand the limitations of the Thomas/Smith (1990) approach, as discussed below.

My first difference with Hennet's calculations has to do with one of the parameters he uses from Thomas (1990). Hennet (2024) uses the $(k_v^c)_{env}$ value of 0.008 hr$^{-1}$ for a pond from Thomas (1990) Table 15-3 (p. 15.20). I concur with Hennet's choice of a pond value versus a river as being more representative of water treatment tanks, but given the discussion above, in my opinion, the lowest $(k_v^c)_{env}$ value in Table 15-3 should have been used – 0.0046 hr$^{-1}$. This

would reduce Hennet's estimates proportionally (0.0046/0.008 times his estimates or 0.58 times his estimates). Applying this to Hennet's values mentioned above (6 to 14% losses across all tanks for the range of VOCs) results in adjusted losses of **3 to 8% losses** (see Exhibit C.2 for calculations).

Further, Thomas suggests that "When one is applying the results of calculations to actual environmental situations, it would probably be advisable to assume that the values of volatilization rate may be high by a factor of ten at most and low by a smaller factor of possibly three." (Thomas, 1990, p. 15-8). Given the disparity between the covered tanks of Camp Lejuene and the assumption of reservoirs open to the atmosphere in Thomas (1990), the calculation errors would obviously be on the high side. Thus, the "high by a factor of ten" is, in my opinion, defensible given the differences between open and closed systems. Applying this to the modified range mentioned above, the new range of VOC losses becomes **0.3 to 0.8%** - closer to the range proposed by AH Environmental. In the absence of a more appropriate estimation approach (and I am not aware of one), in my opinion, this is a more reasonable estimate.

To further support this lower range of estimated volatilization losses, consider that while the Camp Lejeune water treatment tanks are open to water exchange they do not similarly experience air exchange. As new water flows into the tanks, it is exposed to air in the tank that has already been exposed to water with VOCs. This would be analogous to pumping new Coke into a bottle at the same rate Coke flows out of the bottle with a stationary air phase between the Coke and the cover (lid). The Coke is being exchanged with new carbonated Coke, but the air phase above the Coke is not being replaced with fresh air. Thus, the air eventually approaches saturation with $CO_2$ from the previous Coke in the bottle; as this saturation is approached, the driving force for additional $CO_2$ volatilization into the air decreases toward zero (see Section 3.2). In the same way, new water flowing into any storage tank is coming into contact with tank air having increasing levels of VOCs, thereby reducing the driving force for additional volatilization as new water flows into the tank. This understanding of the water treatment tanks' operational nature further supports the low volatilization across these tanks (**0.3 to 0.8% or < 1%** - see Table 5.3).

#### *5.1.3 OTHER POTENTIAL VOC LOSSES (FILTERS, RECARBONATION BASIN, SOLIDS, BACKWASH, DISTRIBUTION)*

Hennet refers to several other potential VOC losses (filters, recarbonation basin, solids, backwash, distribution). While not included in Hennet's overall quantified losses, the suggestion is that these additional losses could have been significant. In my opinion, these potential losses would have been minor to negligible, as discussed below.

##### 5.1.3.1 Sand Filters and Flow-through Recarbonation Basin

Both AH Environmental (2004) and Hennet (2024) estimated that the volatilization losses in sand filters (both Tarawa Terrace and Hadnot Point) and the recarbonation basin without $CO_2$ bubbling (Hadnot Point) were negligible (< 0.1% when adjusting Hennet's estimation for the more appropriate $(k_v^c)_{env}$ as discussed above (see Hennet, 2004, Exhibit 2-4,

p. 5-7 for filters and recarbonation calculations). This is consistent with the flow nature in these basins (versus flow over a weir) along with their short detention times (<0.25 hrs).

#### 5.1.3.2 Recarbonation Basin when $CO_2$ was bubbled up into basin

When installed in 1941/42 the Hadnot Point water treatment recarbonation basin was operational ($CO_2$ was bubbled up into the basin). There is no clear indication of when carbonation ceased, and the unit became a simple flow-through system (AH, 2004; Hennet, 2024). The purpose of recarbonation is to lower the system's pH towards a neutral pH by bubbling $CO_2$ into the bottom of the basin (think of a fish tank with an aerator bubbling air into the fish tank water). In a recarbonation basin, The $CO_2$ reacts with water to form carbonic acid which helps lower the pH of the water.

Hennet states that "the recarbonation of water would likely have removed most (i.e., 90% removal or more) of the dissolved COCs (VOCs) from the water. The aeration of water or air stripping is a well-proven technology to remove VOCs from water." (Hennet, 2024, p. 5-12). While I agree with Hennet's comment that air stripping is a well-proven technology for VOC removal, as demonstrated in standard water treatment textbooks (American Water Works Association - AWWA, 1990; Crittenden et al., 2012), I disagree with Hennet's suggestion of 90% removal during recarbonation. (Interestingly, Hennet does not include this in his final assessment of VOC losses - Hennet, 2024, Exhibit 2-6, p. 5-14). Recarbonation and air stripping are dramatically different processes. Air stripping involves spraying water into the top of a column (think of several shower heads pointing downwards into a column) while blowing air upwards into the bottom of the column, resulting in a very high air to water ratio (commonly A/W of 30:1 or 30 times more air than water – AWWA, 1990; Crittenden et al., 2012). This high A/W ratio greatly increases volatilization (think of pouring coke into a cake pan to increase surface area with a fan blowing air over the top to maximize volatilization). In contrast, in a recarbonation basin, the goal is for CO2 to dissolve into the water; ideally, no $CO_2$ makes it to the surface (think of a fish tank with an air diffuser bubbling air into the water). Functionally, a fraction of the $CO_2$ does make it to the surface, but the $CO_2$ to water ratio (at most 0.05:1 water – Mattingly, 2024) is extremely small relative to the A/W ratio in air stripping (30:1). Thus, recarbonation, with two to three orders of magnitude less A/W ratio, would be orders of magnitude less efficient than air stripping. Further, the low detention time (0.08 hrs – AH, 2004) allowed negligible time for volatilization. All of this combined with the uncertainty of how long recarbonation was implemented causes me to conclude that VOC losses would have been minor, and I agree with Hennet's decision not to include this in his overall VOC loss estimates (Hennet, 2024 - Exhibits 2-4 and 2-6, pp. 5-8, 5-9 and 5-14).

#### 5.1.3.3 Sorption losses onto Spiractor solids

Hennet (2024) suggests that VOC losses may have occurred by sorption onto mineral solids generated in the Spiractor during the softening process (p. 5-12). Hennet points to Schwarzenbach et al. (1993) to support this claim. Generally, when we discuss VOC sorption as a removal process, we talk about sorption onto activated carbon (AWWA, 1990; Crittenden et al., 2012). In contrast, VOC sorption onto mineral surfaces is not discussed as a treatment process in these textbooks. Rather, while the American Water Works textbook (AWWA, 1990)

provides a summary table of heavy metal losses onto softening mineral surfaces, it does not discuss VOC removal onto softening minerals (AWWA, 1990). Upon review of the Schwarzenbach et al. reference (1993), I note that their mention of organic removal onto mineral surfaces is directed at highly hydrophobic organic solutes (versus our slightly hydrophobic VOCs) and high surface area minerals (e.g., 100s of $m^2/g$ – it is unlikely that Spiractor solids would approach this level). This combined with the low detention time in the Spiractor (23.08 m3 / 157.73 m3/h = 0.15 hrs – AH Environmental, 2004) versus the typical 24-hour equilibration time in sorption studies like those reported in Schwarzenbach et al. (1993) leads me to conclude that such losses would be negligible in the Camp Lejeune case. I thus concur with Hennet's decision not to include this in his overall VOC loss estimates (Hennet, 2024 - Exhibits 2-4 and 2-6, pp. 5-8, 5-9 and 5-14).

##### 5.1.3.4 Losses in backwash water

Hennet refers to filter backwashing as a possible source of VOC loss in the Camp Lejeune treatment plants (Hennet, 2024, p. 5-13). Hennet indicates that the filters are backwashed every 48 hours. Typically, backwash is for 20-30 mins (0.33 to 0.5 hrs) with water flowing upwards at 3 to 4 times the filtration rate to cause filter bed expansion and enhance filter cleaning (AWWA, 1990; Crittenden et al., 2012). Using the longer filtration time and lower backwash rate leads to backwashing occurring for ~1% of the time (0.5 hr / 48 hours) at 3 times the rate, or backwash water accounts for roughly 3% of the treated water. Often, this water is sent to a settling basin to allow the solids to settle out of the water. After settling, the water may be returned to the plant for treatment. Some of the VOCs may be lost due to volatilization, and some of the water may be lost due to evaporation and association with the solids in the settling basins. In this case, the volatilization losses may be closer to those estimated by Hennet for tanks as the settling basins are open to the atmosphere (Hennet estimated from 1 to 10% for the various VOCs – see Section 5.1.2). Using the high end of losses to the atmosphere (10%) and assuming 100% of the backwash water is recoverable and recycled to the water treatment plant (which is 3% of the total water treated) leads to at most 10%*3% or 0.3% VOC losses of the overall treated water. I thus conclude that these losses would be minor and concur with Hennet's decision not to include this in his overall VOC loss estimates (Hennet, 2024 - Exhibits 2-4 and 2-6, pp. 5-8, 5-9 and 5-14).

##### 5.1.3.5 Losses in the distribution system

After treatment and storage, the water is delivered to the consumer through the distribution system. Flow in the distribution is through pressurized pipes and thus not open to the atmosphere. AH Environmental (2004) and Hennet (2024) do not consider losses in the distribution system. Given that the distribution system is closed and pressurized, I likewise conclude that losses in the distribution system were negligible.

#### *5.1.4 Summary of VOC losses in water treatment plant storage, treatment, and distribution*

In Table 5.3, I summarize my conclusions regarding the likely VOC losses in the Spiractor softening basin, the closed storage tanks (raw water, clearwell, water towers), and other

possible losses in the water treatment systems at Camp Lejeune. AH Environmental suggested an overall loss of <15% based on their calculations for PCE and TCE. Based on Table 5.3, I would suggest that the estimated losses for TCE, PCE, 1,2-tDCE and Bz is actually <10% with only VC slightly above this 10% level but still less than the 15 % suggested by AH Environmental. I thus conclude that AH Environmental was conservative in their estimate of less than 15% PCE/TCE losses.

In contrast, Hennet (2024) estimated higher losses than AH Environmental (Table 5.3). The reasons for Hennet's higher estimates are discussed in Sections 5.1.1 and 5.1.2, along with reasons for why my estimates deviate from Hennet's estimates. (In short, Hennet overestimated the water drop in the Spiractor and used a method that assumed tanks were open to the atmosphere). **As such, I conclude that Hennet (2024) overestimated the potential losses in the water treatment processes. The actual loss values, in my opinion, were less than 6 to 12% for the VOCs of interest versus 15% to 32% as suggested by Hennet (2024). Table 5.4 shows how these volatilization losses would reduce raw water to treated water concentrations.**

Table 5.3 – Summary of VOC Loss Estimates for Spiractor, Storage Tanks, and Other Losses for Camp Lejeune – Tarawa Terrace and Hadnot Point Water Treatment Systems

| Source | TCE (%) | PCE (%) | 1,2-tDCE (%) | VC (%) | Bz (%) |
|---|---|---|---|---|---|
| Spiractor (Sec 5.1.1) | 5.2 | 6.2 | 5.9 | 9.9 | 4.3 |
| Storage tanks (Sec 5.1.2) | <1 | <1 | <1 | <1 | <1 |
| Other losses (Sec 5.1.3) | <1 | <1 | <1 | <1 | <1 |
| **My Estimate - overall losses** | **<7.2** | **<8.2** | **<7.9** | **<11.9** | **<6.3** |
| AH Environmental (2004), p.5-1 | <15 | <15 | - | - | - |
| Hennet (2024), Exhibit 2-6, p.5.14 | 17 | 18 | 22 | 32 | 15 |

**Table 5.4 – VOC Concentrations in Treated Water Considering Volatilization Losses**

| Source | TCE (%) | PCE (%) | 1,2-tDCE (%) | VC (%) | Bz (%) |
|---|---|---|---|---|---|
| VOC in Raw Water | 100 | 100 | 100 | 100 | 100 |
| VOC in Treated Water | 93 | 92 | 92 | 88 | 94 |

### 5.2 The ATSDR models indirectly accounted for VOC losses during water treatment, storage, and distribution (in response to Hennet's Opinion 10 that losses were not accounted for - Hennet, 2024, p. 5-36)

Hennet (2024) suggests that ATSDR considered only raw water before treatment in its system modeling approach, concluding that "concentration estimates by ATSDR are therefore not representative of the treated water and exaggerate the COC concentration in the drinking water supply." (Hennet, 2024, p. 5-37). In fact, in his expert report, Maslia points out that "The reconstructed concentrations versus the observed data in Table 7.15 (Table 5-5 in this report) demonstrate successful Level 4 calibration," indicating that treated water samples were used in

the final calibration step for Hadnot Point. The footnotes in Table 5-5 indicate which samples were of untreated water, treated water, and unknown treatment status (eight fell into this last category). Of the twelve samples with known treatment status, nine were of treated water, and three were of untreated water, demonstrating that treated water and associated VOC losses in the treatment plant were well represented in the Level 4 calibration step.

Further evaluation of Table 5-5 provides insight into the fate of VOCs in the Hadnot Point water treatment plant. On three occasions, water samples were taken from the raw water entering the treatment plant and the finished water after treatment. For TCE the dates were 7/27/82 and 12/4/84, while for 1-2-tDCE the date was 12/4/84. In all three cases, the treated concentrations were similar to or higher than the raw water concentrations. While admittedly a small data set, the data do provide further support for the minor to negligible VOC losses I propose in Section 5.1 and my assertion that Hennet overestimated these losses.

Table 5-5: Summary of measured and reconstructed contaminant concentrations used in the Level 4 calibration for Hadnot Point (Maslia, 2024, Table 7.15, p. 86)

| Contaminant | [1]Measured data | | [2]Reconstructed (simulated) | | [2]Reconstructed (maximum value) | |
|---|---|---|---|---|---|---|
| | Sample date | Concentration, in µg/L | Simulation date | Concentration, in µg/L | Simulation date | Concentration, in µg/L |
| PCE | 5/27/1982[3] | 15 | May 1982 | 21 | Nov. 1983 | 39 |
| | 7/27/1982[4] | 100 | July 1982 | 27 | | |
| | 12/4/1984[6] | 3.9J | Nov. 1984 | 31 | | |
| | 2/5/1985[7] | 7.5J | Jan. 1985 | 16 | | |
| TCE | 5/27/1982[3] | 1,400 | May 1982 | 438 | Nov. 1983 | 783 |
| | 7/27/1982[5] | 19 | Aug. 1982 | 670 | | |
| | 7/27/1982[6] | 21 | Aug. 1982 | 670 | | |
| | 12/4/1984[5] | 46 | Nov. 1984 | 639 | | |
| | 12/4/1984[6] | 200 | Nov. 1984 | 639 | | |
| | 12/12/1984[6] | 2.3J | Dec. 1984 | 43 | | |
| | 12/19/1984 | 1.2 | Dec. 1984 | 43 | | |
| | 2/5/1985[7] | 429 | Jan. 1985 | 324 | | |
| 1,2-tDCE | 12/4/1984[6] | 83 | Nov. 1984 | 358 | Nov. 1983 | 435 |
| | 12/4/1984[5] | 15 | Dec. 1984 | 26 | | |
| | 12/12/1984[6] | 2.3J | Dec. 1984 | 26 | | |
| | 2/5/1985[7] | 150 | Jan. 1985 | 163 | | |
| VC | 2/5/1985[7] | 2.9J | Jan. 1985 | 31 | Nov. 1983 | 67 |
| Benzene | 11/19/1985[7,8,9] | 2,500 | Nov. 1985 | 3 | Apr. 1984 | 12 |
| | 12/10/1985[7] | 38 | Dec. 1985 | 3 | | |
| | 12/18/1985[7] | 1.0 | Dec. 1985 | 3 | | |

[1] Data from Faye et al. (2010, Tables C11 and C12)

[2] Simulation results represent the last day of each month (e.g., May 31); results reported for simulation month nearest the sample date; refer to Appendix A7 for complete listing of reconstructed finished-water concentrations

[3] Water sample collected at Building NH-1; data reported as unreliable

[4] Water sample collected at Building FC-530

[5] Untreated water

[6] Treated water

[7] Treatment status unknown

[8] Laboratory analysis noted with: "Sample appears to have been contaminated with benzene, toluene, and methyl chloride" (JTC Environmental Consultants 1985)

[9] Data noted with: "Not Representative" (U.S. Marine Corp Base Camp Lejeune Water Document CLW #1356)

Likewise, for Tarawa Terrace, Maslia (2024) indicates that "The results of these computations compared to an analysis of a water sample collected at a point in time, either at the TTWTP or at a location within the TT water-distribution system such as an outdoor or indoor faucet, are summarized in Table 7.12." (Maslia, 2024, p. 58, with Table 7.12 on p. 60 of his report). Data coming from indoor or outdoor faucets would reflect treated water. Once again, the fact that Tarawa Terrace Level 4 calibration included treated water samples demonstrates that ATSDR indirectly considered losses during water treatment and distribution.

While Maslia's Table 7.12 (2024) does not identify raw versus treated water that can be compared for VOC losses across the treatment process, from CLW 606 we know that the 7/28/82 samples allow a comparison. For the 7/28/82 PCE samples, the raw water was 76 ug/l and the treated water was 82 ug/L (considering analytical error, the same), once again supporting my opinion in Section 5.1 that the treatment processes at Camp Lejeune would produce at most minor VOC losses, if any, and that Hennet (2024) overestimated these losses.

**Thus, for both the Tarawa Terrace and Hadnot Point systems, treated water samples were used in the calibration process and the ATSDR did consider such losses in the treatment system.**

### 5.3 HENNET (2024) OVERESTIMATED VOC LOSSES IN THE MOBILE FIELD WATER TANKS (WATER BUFFALOES). WATER CONCENTRATIONS IN THE WATER BUFFALOES WERE ONLY <u>MODERATELY</u> LOWER THAN IN THE WATER TREATMENT PLANTS' TREATED WATER. (IN RESPONSE TO HENNET'S OPINION 13, THAT THEY WERE <u>SUBSTANTIALLY</u> LOWER - HENNET, 2024, P. 5-39).

Hennet (2024) assesses volatilization losses during the filling of water buffaloes (mobile storage tanks) used for water provision in areas of the base not serviced by the water distribution system (*e.g.*, during training exercises). Hennet's estimates are based on water buffalo diagrams (Exhibit 13-1, p. 5-39, and Attachment C, p. C-15; Hennet, 2024) as shown in Figure 5.2 in this report. Hennet assumes that the water buffaloes were filled through the filler pipe which has a strainer through which water would flow (Figure 5.2). Hennet assumes that water flowing through the strainer would be like water coming out of a shower head, and uses the McKone and Knezovich (1991) analysis for TCE losses in a shower. In adapting this approach for losses in filling the water buffaloes, Hennet (2024) modified TCE mass transfer coefficients as per McKone and Knezovich (1991), assuming that these mass transfer rates apply until the tank is half full, at which point the filling hose becomes submerged. At this point, Hennet assumes a linear decrease in removal rate during the second half of the tank filling (see Hennet, 2024, Exhibit 13-2, p. 5-41). Using this approach, Hennet estimates VOC losses in the water buffaloes as summarized in the Rows 1 and 2 of Table 5-6.

Assuming the tank was filled through the filler pipe and strainer, an assumption addressed further below, there are fundamental differences between the shower and buffalo systems that Hennet does not address, namely time for volatilization and cross sectional area for mass transfer. Relative to time of volatilization, the shower-based VOC loss is for a 1.6 m drop from the showerhead to the bathtub (McKone and Knezovich, 1991, Table 1). As Hennet (2024) points out, the water buffaloes are 0.8 m tall (see upper table in Figure 5-2). During

initial filling, the entire 0.8 m fall would be experienced. As the tank approaches full, the fall height approaches zero (in contrast, during the shower experiment, the fall height remains 1.6 m throughout and the air to water remains the same since the water drains). As such, during filling, the water buffalo would have an average fall height of 0.4 m, which is 1/4th (25%) of that in the shower experiment. Assuming that the shower and strainer produce similar spray patterns with similar downward velocities, and given that the relative time for volatilization is the fall distance divided by downward velocity, since the downward velocities are assumed to be the same, the relative time for volatilization is proportional to the relative fall heights (the velocities cancel out in the ratio). Assuming the strainer produces a similar spray pattern (cross-sectional area) to the shower, no adjustment is necessary for the mass transfer area in this case. Thus, my VOC loss estimate in Table 5-6, Row 3 is ¼ (0.4 m / 1.6 m) or 25% of what Hennet estimates in Row 1 of the same table, which I apply to filling of the tank. If the strainer produced a smaller degree of spray relative to the shower the losses would be reduced, further supporting my lower estimate compared to Hennet's.

**Water Buffalo Dimensions**

| | | |
|---|---|---|
| M107A2 | model | |
| 400 | gal | volume |
| 17.125 | inches | manhole diameter |
| 4.625 | inches | filler pipe cover gasket outer diameter |
| 3.75 | inches | filler pipe cover gasket inner diameter |
| 31.97 | inches | tank height |
| 0.81 | meters | tank height |
| 16.1 | inches | strainer length |
| 0.41 | meters | strainer length |


References:

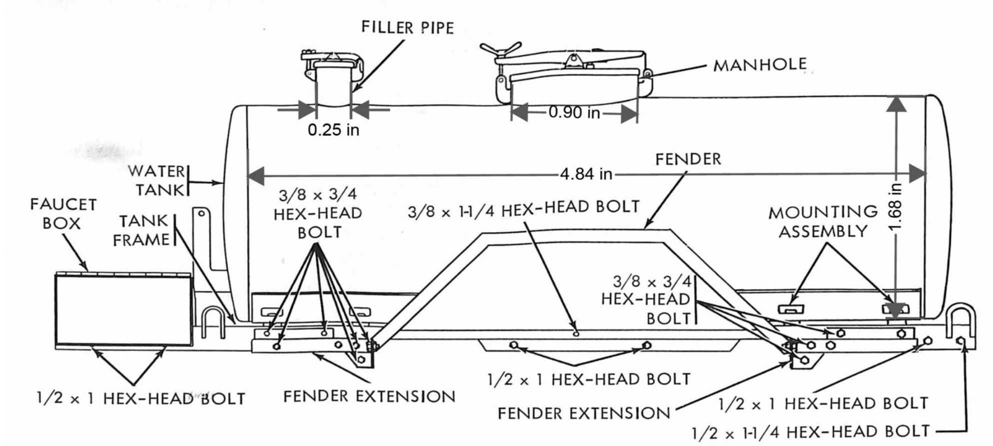
ATSDR_WATERMODELING_01-0000917100 - ATSDR_WATERMODELING_01-0000917102

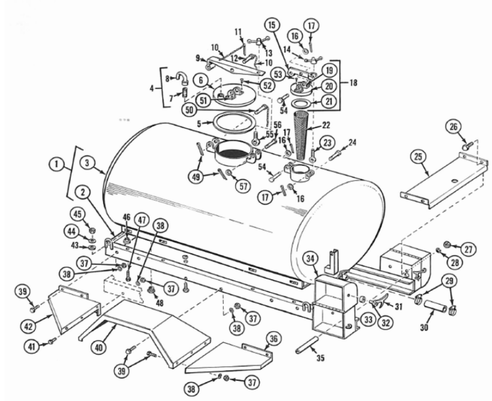
Department of the Army. 1964. Operator, Organizational and Field Maintenance Instructions, Including Repair Parts and Special Tools List-for: CHASSIS TRAILER: 1 1/2 TON, 2-WHEEL M103A1, M103A2, M103A3, M103A3C, M103A4, AND M103A4C TRAILER, CARGO: 1 1/2 TON, 2-WHEEL M104, M104A1, M105A1, M105A2, AND M105A2C TRAILER, TANK, WATER: 1 1/2 TON, 2-WHEEL M106, M106A1, M107A1, M107A2, AND M107A2C TRAILER, VAN, SHOP: FOLDING SIDES, 1 1/2 TON, 2-WHEEL, M448. TM 9-2330-213-14. January.

DODParts.com. NSN 4730-00-546-5898 Sediment Strainer Element <https://dodparts.com/nsn/4730-00-546-5898>. Accessed November 21, 2024.

DODParts.com. NSN 5330-00-314-0759 Gasket <https://dodparts.com/nsn/5330-00-314-0759>. Accessed November 21, 2024.

DODParts.com. NSN 2510-00-741-2233 Manhole Cover <https://dodparts.com/nsn/2510-00-741-2233>. Accessed November 21, 2024.

NON-SUPPLY ITEMS

| KEY ITEM | PART NO. | KEY ITEM | PART NO. |
|---|---|---|---|
| 1 - TANK ASSY | 8384144 | 35 - WASHER | 446178 |
| 2 - FRAME | 8384143 | 36 - EXTENSION | 8384134 |
| 3 - TANK | 8384097 | 37 - NUT | 120371 |
| 6 - COVER | 7979648 | 38 - WASHER | 120384 |
| 15 - HINGE | 7979622 | 39 - SCREW | 123605 |
| 16 - WASHER | 120394 | 40 - FENDER | 8384138 |
| 17 - PIN | 121222 | 41 - SCREW | 120424 |
| 19 - BRACKET | 7979666 | 42 - EXTENSION | 8384133 |
| 20 - COVER | 7979665 | 44 - WASHER | 8384130 |
| 21 - GASKET | 7979667 | 45 - NUT | 451027 |
| 23 - BOLT | 7979634 | 47 - SCREW | 428736 |
| 25 - PLATE | 8331227 | 49 - PIN | 187988 |
| 26 - SCREW | 123520 | 50 - PIN | 7412295 |
| 27 - NUT | 120369 | 51 - BRACKET | 7979647 |
| 28 - WASHER | 120382 | 52 - RIVET | 142880 |
| 29 - CLAMP | 8365414 | 53 - RIVET | 588384 |
| 32 - PIN | 8331226 | 57 - WASHER | 120396 |
| 33 - SPACER | 8384102 | | |
| 34 - COVER | 8384106 | | |

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FIGURE 133. WATER TANK, TANK FRAME, AND RELATED PARTS - (M106A1, M107A1, M107A2, M107A2C).

| (1) ILLUST (a) FIG NO | (b) ITEM NO | (2) SOURCE, MAINT AND RECOVERABILITY CODE (a) MATERIEL CODE | (b) SOURCE | (c) MAINTENANCE LEVEL | (d) RECOVERABILITY | (3) FEDERAL STOCK NO | (4) DESCRIPTION | (5) UNIT OF ISSUE | (6) QTY INC IN UNIT | (7) 15-DAY MAINTENANCE ALLOWANCE PER 100 EQUIPMENTS (a) CO OR BTRY | (b) SEP CO SEP BN OR REGT | (c) 3RD ECH (DIR SUP) | (d) 4TH ECH (GEN SUP) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | WATER TANK, TANK FRAME, AND RELATED PARTS - (M106A1, M107A1, M107A2, and M107A2C) (Fig. 133) | | | | | | |
| 133 | 4 | | P1 | O | | 2510-741-2233 | COVER: (7412233) | ea | 1 | | | | |
| 133 | 5 | | P | O | | 2510-741-2242 | GASKET: (7412242) | ea | 1 | | | | |
| 133 | 7 | | P1 | O | | 4730-741-2249 | NIPPLE: (7412249) | ea | 1 | | | | |
| 133 | 8 | | P1 | O | | 2510-703-9760 | BEND: (7039760) | ea | 1 | | | | |
| 133 | 9 | | P | O | | 2510-741-2247 | HINGE: (7412247) | ea | 1 | | | | |
| 133 | 10 | 55 | P | O | | 4010-186-9403 | CHAIN: 6 in. (42-C-16887) | ft | ≠ | | | | |
| 133 | 11 | | P | O | | 5315-059-0210 | PIN, COTTER: (96906-24665-504) | ea | 1 | | | | |
| 133 | 12 | | P | O | | 2540-741-2283 | PIN AND CHAIN ASSEMBLY: (7412283) | ea | 2 | | | | |
| 133 | 13 | | P | O | | 5310-741-2276 | NUT, PLAIN, WING: (7412276) | ea | 1 | | | | |
| 133 | 14 | | P | O | | 5310-050-3103 | NUT, PLAIN, WING: (503103) | ea | 1 | | | | |
| 133 | 18 | | P1 | O | | 2510-741-2234 | COVER: w/HINGE, assembly (7412234) | ea | 1 | | | | |
| 133 | 22 | | P | O | | 4730-546-5898 | STRAINER ELEMENT, SEDIMENT: (8735825) | ea | 1 | | | | |
| 133 | 24 | | P | O | | 5315-741-2285 | PIN, STRAIGHT, HEADED: (7412285) | ea | 1 | | | | |
| 133 | 30 | | P | O | | 4720-278-4895 | HOSE, RUBBER: (8330817) | ea | 1 | | | | |
| 133 | 31 | | P | O | | 2540-040-2414 | LOCK: (8330823) | ea | 1 | | | | |
| 133 | 35 | 5 | P | F | | 4462-607-0001 | PIPE, STEEL: galvenized, std. wt., 1-1/4 in. | ft | ≠ | | | | |
| 133 | 43 | | P | F | | 5330-575-9791 | WASHER, NONMETALLIC: (8331544) | ea | 8 | | | | |
| 133 | 46 | | P | O | | 5340-537-2212 | MOUNT, RESILIENT: (8331543) | ea | 8 | | | | |
| 133 | 48 | | P | O | | 4730-525-7160 | PLUG, PIPE: (8735929) | ea | 1 | | | | |
| 133 | 48 | | P | O | | 4730-703-9752 | PLUG, PIPE: (7039752) | ea | 1 | | | | |
| 133 | 54 | | P | O | | 5315-741-2286 | PIN: (7412286) | ea | 2 | | | | |
| 133 | 55 | | P | O | | 5306-741-2228 | BOLT, EYE: (7412228) | ea | 1 | | | | |
| 133 | 56 | | P | O | | 5320-014-2390 | RIVET SOLID: (142390) | ea | 1 | | | | |
| | | | P | F | | 8010-533-9687 | PARTS KIT, WATER TANK INTERIOR COATING (5702157) COMPOSED OF: 2 QTS EPON COATING RW-100-1A 2 QTS EPON COATING RW-100-1B | ea | ≠ | | | | |

Figure 5-2 – Schematic of Water Buffalo showing filler pipe (top figure) and strainer (#22 in lower figure and listed in the table) – Hennet, 2024, p. C-15. Note: Redline dimensions on Hennet's water buffalo diagram are in error, refer to upper table for dimensions.

Table 5.6 – Hennet Estimates of VOC Losses in water buffaloes based on filling through strainer using shower analysis of McKone and Knezovich (1991) (Exhibit 12-3, p. 5-41, Hennet, 2024), and my modifications to Hennet's estimates

| Source | TCE (%) | PCE (%) | 1,2-tDCE (%) | VC (%) | Bz (%) |
|---|---|---|---|---|---|
| (1) Hennet – Losses during filling of bottom half of water tank – based on shower losses | 54 | 58 | 72 | 81 | 60 |
| (2) Hennet – Overall loss (assumes linear decrease in loss during filling top half of tank) | 41 | 44 | 54 | 61 | 45 |
| (3) My estimate of losses during filling tank based on average fall height of 0.4 m vs 1.6 m in shower experiment, assuming downward velocities are the same (25% or 0.25 x Row 1) | 14 | 15 | 18 | 20 | 15 |
| (4) My estimate of maximum possible equilibrium losses when tank half full* | 23 | 35 | 24 | 47 | 16 |

*Exhibit C.3

Another critique of Hennet's use of the McKone and Knezovich (1991) shower analysis is that it is based on kinetics of mass transfer (volatilization) in a shower setting where the system has much more air than water. When the water buffalo is one-half full, the air-to-water ratio is 1:1. In contrast, during the shower experiments, the shower air-to-shower water ratio was more than 12:1 (McKone and Knezovich, 1991 reported 2.3 $m^3$ of air versus 0.19 $m^3$ of water in their experiments). Even this calculated 12:1 air-to-water ratio overestimates the experimental air-to-water ratio; since the water exited through the shower drain rather than accumulating in the tub, the actual air-to-water ratio was much higher. In Table 5.6, I included a row (Row 4) of Henry's Law-based equilibrium losses of the VOCs when the tank was half full – this is the maximum that could be achieved if sufficient time were present to reach equilibrium. Looking at Table 5.6, one notes that Hennet's loss values in filling the bottom half of the tank (Row 1) exceed my equilibrium calculations (Row 4). How can kinetic-based experiments generate higher losses than equilibrium allows? This can be attributed to the fact that the shower experiments had a much higher air-to-water ratio (>12:1) than the water buffalo at half full (1:1). The shower analysis would thus be analogous to a Coke bottle with only a small amount of Coke in the bottom versus the tank analysis based on half full. Had the shower experiments been conducted at a 1:1 water ratio, the losses would have been much lower – even lower than my equilibrium predictions due to mass transfer/volatilization limitations (Section 3-2). This further supports my loss estimates in Row 3, which are all below the equilibrium loss values in Row 4.

Consider the case where water buffaloes were filled through the manhole on top of the water buffalo (Figure 5.2), which seems highly likely for reasons discussed below and in Sabatini Appendix A. For filling through the manhole, the shower-based method would further overestimate VOC removal (the flow would not go through the strainer in the filler pipe). It is not apparent why highly treated water would be put through the strainer. The strainer would more likely be used during field deployment when, in the absence of a treatment plant, the water buffaloes would be filled from a lake or river, and the strainer would remove debris. This is consistent with the presence of a hand pump feeding the filler pipe in early versions of the water buffaloes (Brigham, 2024, Exhibit 32, p. 98), which is absent in later versions of the water buffaloes (Brigham, 2024, Exhibit 35, p. 101). Brigham indicates that at Camp Lejeune, the water buffaloes were filled from standpipes (Brigham, 2024, Exhibit 36 and 37, pp. 103 and 104, respectively), which were 2-inch vertical pipes directly tapping into the water distribution system. The vertical standpipe had two 90-degree elbows and a downspout tube length allowing the water buffaloes to be filled from above (as illustrated in Figure 24 in Sabatini Appendix A, which is attached to this rebuttal report). Sautner et al. indicate that the Hadnot Point distribution system had 60 psi of pressure (Sautner et al., 2013, Figure S8.11, p. S8.16); this and the standpipe configuration are consistent with a reported fill time of two to three minutes (Sabatini Appendix A), and thus a flow rate of 150 to 200 gpm (400 gallons / 200 gallons/minute = 2.0 minutes fill time). For ease of filling and to accommodate this higher flow rate, it seems likely that the water buffaloes would be filled through the manhole (the filler pipe strainer would likely not accommodate these high flow rates). Testimonials from Camp Lejeune employees document that water buffaloes were filled through the manhole cover (Sabatini Appendix A).

Standpipe filling through the manhole cover leads to two additional deviations from Hennet's (2024) calculation. First, since the flow does not go through the strainer, the downward stream of water coming from the 2-inch standpipe/hose would have lower area for mass transfer than in the shower-based estimate. While the standpipe is 2 inches in diameter (Brigham, 2024), the water buffalo filler pipe has an inside diameter of 3.75 inches (Hennet, 2024, p. C-15, inset table – see Figure 5-2) which combined with the strainer produces a larger spray area. The diameter of a shower spray, the basis of Hennet's shower-based loss estimates, is approximately 6 to 7 inches midway between the showerhead to the floor (Sabatini, 2025). Thus, the shower-based volatilization values have at least three times the surface area (6 inches versus 2 inches) for mass transfer versus top-filling through the manhole sans the strainer, and the resulting VOC losses for manhole filling would be 1/3 (0.33 times) of Hennet's estimate relative to area for mass transfer.

Another deviation from Hennet's shower analysis is the relative time of volatilization. For the higher flow rates when filling through the manhole (standpipe flow rates of 150 to 200 gpm), and based on the cross-sectional area of a 2-inch pipe, the downward velocities when filling through the manhole would be 15 to 20 ft/sec (velocity = flow / area). In contrast, the shower-head-induced energy losses would generate lower downward velocities in the shower – approximately 10 to 13 ft/sec (Sabatini, 2025). Thus, the downward velocities in filling the water tank would be approximately 1.5 times higher during manhole filling versus in the

shower/strainer system. Since the volatilization time is inversely proportional to downward velocity (time = distance / velocity), the filling time would be reduced by dividing shower results by 1.5 (or multiplying by 1/1.5 or 0.66). Thus, Hennet's VOC losses must be reduced for the lower surface area discussed above (0.333), and volatilization time (relative fall height (0.4 m/1.6m or 0.25) / relative velocities (1.5) = 0.167) in manhole filling). My estimated manhole filling losses, accounting for area of mass transfer and volatilization time, become 0.333*0.167 = 0.056 or 5.6% of Hennet's values in Table 5.6, Row 1 (see Table 5.7, Row 3 for my estimated losses).

Sabatini Appendix A indicates that water buffaloes were sometimes filled from fire hydrants, which would accommodate larger hoses and higher flow rates (at least twice my flow rates above – Sabatini Appendix A). Increasing the flow rates would decrease my loss estimates proportionally (e.g., doubling the flow rate would reduce my loss estimates in half). In this case and others, Sabatini Appendix A indicates that filling tubes were sometimes inserted into the tank, which would reduce fall height, volatilization times, and VOC losses proportionally, again reducing my estimated losses in Table 5.7, Row 3.

In addition to my estimate for losses during manhole filling (Table 5.7, Row 3 is 5.6% of Hennet's Row 1 in Table 5.6). Table 5.7 also summarizes shower-based VOC losses through filler pipe/strainer by Hennet and by myself (Row 1 and 2, respectively). The data in Table 5.7 demonstrate that necessary adjustments to the shower-based approach to more closely mimic water buffalo filling result in significantly lower VOC loss estimates than Hennet (true for both filler-pipe and manhole filling).

As one final step in the analysis, the minor losses during the filling process estimated here raise the question of what losses might have occurred in the water buffalo headspace during daily operation. We return to the Thomas (1990) approach discussed earlier for water treatment system tanks to address this question. Since the water buffalo drains and the headspace increases during the day, the Thomas approach, while not exact, is more directly applicable. Assuming that the tank is filled (full) first thing in the morning and is used from morning to evening, the operating time could be as much as 12 hours (7 AM to 7 PM). During initial use, minimal volatilization losses would have been experienced, while the maximum volatilization would have occurred after twelve hours. As such, the average volatilization losses during operation would occur at the mid-point in time – after six hours. Row 4 in Table 5.7 summarizes VOC loss estimates during water buffalo use based on this analysis (see Exhibit C.4 for details). My analysis assumes the water buffaloes were filled and used only once per day – if they were filled twice per day, my estimate would be reduced in half.

Table 5.7 provides a summary of the overall VOC losses in the water buffaloes based on Hennet's (2024) calculations and my estimates for filling the water buffaloes from the filler tank and also my analysis for filling from the manhole cover. **I thus conclude that Hennet's calculations overestimated the VOC losses during filling of the water buffaloes; he estimated 41% to 61% for the range of VOCs while I estimated much lower losses (15 to 22% through filler pipe/strainer and 4.2 to 6.7% through the manhole, including daily use not accounted for by Hennet) for the range of VOCs. I thus conclude that the water buffalo**

**water was only mildly to moderately lower in VOCs, not substantially lower as Hennet (2024) states. Table 5.8 shows how these volatilization losses would impact raw water to treated water as well as treated water to water buffalo filling through filler pipe/strainer and through the manhole, both including losses during use (not accounted for in Hennet, 2024). Again, only minor to moderate losses are realized in the water buffaloes.**

Table 5.7 – Summary of my estimates of VOC losses in filling water buffaloes versus Hennet's Estimates (Hennet, 2024)

| **Source** | **TCE (%)** | **PCE (%)** | **1,2-tDCE (%)** | **VC (%)** | **Bz (%)** |
|---|---|---|---|---|---|
| (1) Hennet – filler pipe/strainer - Overall loss (see Table 5-6, Row 2)) | 41 | 44 | 54 | 61 | 45 |
| (2) My estimate – filler pipe/strainer overall filling losses (see Table 5.6, Row 3) | 14 | 15 | 18 | 20 | 15 |
| (3) My estimate – filled by standpipe through manhole cover – 5.6% of Hennet's Row 1 values in Table 5.6 | 3.0 | 3.2 | 4.0 | 4.5 | 3.3 |
| (4) My estimated losses during daily use of water buffaloes (Exhibit C.4) | 1.2 | 1.0 | 1.9 | 2.2 | 1.2 |
| (5) My estimate – overall losses – filler pipe strainer plus daily use (Row 2+4) | 15 | 16 | 20 | 22 | 16 |
| (6) My estimate – overall losses – standpipe filling through manhole plus daily use (Row 3+4) | 4.2 | 4.2 | 5.9 | 6.7 | 4.5 |

Table 5.8 – VOC Concentrations in Treated Water and During Water Buffalo Filling / Use Considering Volatilization Losses

| **Source** | **TCE (%)** | **PCE (%)** | **1,2-tDCE (%)** | **VC (%)** | **Bz (%)** |
|---|---|---|---|---|---|
| VOC in Raw Water | 100 | 100 | 100 | 100 | 100 |
| VOC in Treated Water (Table 5.4) | 93 | 92 | 92 | 88 | 94 |
| VOC in Buffalo Water – filling through filler tube/strainer and daily use (Table 5.7, Row 5) | 79 | 77 | 74 | 69 | 79 |
| VOC in Buffalo Water - standpipe filling through manhole and daily use (Table 5.7, Row 6) | 89 | 88 | 87 | 82 | 90 |

**Exhibit A**

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**Exhibit C.1**

**Calculations for Spiractor – 1 ft (0.3 m) Water Drop / Corrected Equation / All Five VOCs**

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Spiractors** | | | | | | | | |
| Chemical Properties | | | | | | | Spiractor Properties | |
| | | PCE | TCE | 1,2tDCE | VC | Bz | | |
| | | | | | | | Tailwater (m) - h | 0.15 |
| H | atm-m3/mol) | 1.31E-02 | 7.07E-03 | 7.42E-03 | 2.17E-02 | 4.36E-03 | Circumference (m) | 0.94 |
| R | tm-m2/(mol-K) | 8.21E-05 | 8.21E-05 | 8.21E-05 | 8.21E-05 | 8.21E-05 | Flow (m^3/hr) | 157.73 |
| T | K | 2.93E+02 | 2.93E+02 | 2.93E+02 | 2.93E+02 | 2.93E+02 | Flow/Circumf (m^2/hr) - q | 167.80 |
| H' | dimensionless | 5.44E-01 | 2.94E-01 | 3.08E-01 | 9.02E-01 | 1.81E-01 | Critical Depth above weir (m) | 0.05 |
| Dw | cm2/s | 7.59E-06 | 8.43E-06 | 1.17E-05 | 1.38E-05 | 8.99E-06 | | |
| Da | cm2/s | 8.13E-02 | 8.90E-02 | 8.65E-02 | 1.03E-01 | 9.80E-02 | | |
| MW | g/mol | 1.66E+02 | 1.31E+02 | 96.90 | 6.25E+01 | 7.81E+01 | | |
| (D)O2,w | cm2/s | 8.99E-06 | 8.99E-06 | 8.99E-06 | 8.99E-06 | 8.99E-06 | | |
| (D)O2,a | cm2/s | 9.80E-02 | 9.80E-02 | 9.80E-02 | 9.80E-02 | 9.80E-02 | | |
| | | | | | | | | |
| Hennet | | | | | | | | |
| Fall Ht (m) | 3.00E-01 | Z = Fall Ht + 1.5*critical depth (m) | | | **3.75E-01** | | | |
| | | | | | | | | |
| Deficit Ratio (ln r - AH Eq 11 corrected | dimensionless | 1.08E-01 | 1.08E-01 | 1.08E-01 | 1.08E-01 | 1.08E-01 | | |
| Liquid Mass Transfer - kL - AH Eq 10 | m/s | 1.20E-02 | 1.29E-02 | 1.60E-02 | 1.78E-02 | 1.34E-02 | | |
| Gas Mass Transfer - kg - AH Eq 9 | m/s | 4.42E-02 | 4.69E-02 | 4.60E-02 | 5.17E-02 | 5.00E-02 | | |
| Overall Mass Transfer - Ko - AH Eq 8 | m/s | 8.01E-03 | 6.66E-03 | 7.52E-03 | 1.29E-02 | 5.41E-03 | | |
| Fraction remaining - Ci/Co - AH Eq 7 | dimensionless | 0.938 | 0.948 | 0.941 | 0.901 | 0.957 | | |
| **Removal % (1 - (Ci/Co) *100** | **%** | **6.2** | **5.2** | **5.9** | **9.9** | **4.3** | | |

## Exhibit C.2

## Calculations for Water Tank Losses – Hadnot Point / Tarawa Terrace

| Tanks - Thomas/Smith Approach - Hadnot Point | | | | | | |
|---|---|---|---|---|---|---|
| Chemical Properties | | PCE | TCE | 1,2tDCE | VC | Bz |
| H | atm-m3/mol) | 1.31E-02 | 7.07E-03 | 7.42E-03 | 2.17E-02 | 4.36E-03 |
| R | tm-m2/(mol-K) | 8.21E-05 | 8.21E-05 | 8.21E-05 | 8.21E-05 | 8.21E-05 |
| T | K | 2.93E+02 | 2.93E+02 | 2.93E+02 | 2.93E+02 | 2.93E+02 |
| H' | dimensionless | 5.44E-01 | 2.94E-01 | 3.08E-01 | 9.02E-01 | 1.81E-01 |
| Dw | cm2/s | 7.59E-06 | 8.43E-06 | 1.17E-05 | 1.38E-05 | 8.99E-06 |
| Da | cm2/s | 8.13E-02 | 8.90E-02 | 8.65E-02 | 1.03E-01 | 9.80E-02 |
| MW | g/mol | 1.66E+02 | 1.31E+02 | 96.90 | 6.25E+01 | 7.81E+01 |
| (D)O2,w | cm2/s | 8.99E-06 | 8.99E-06 | 8.99E-06 | 8.99E-06 | 8.99E-06 |
| (D)O2,a | cm2/s | 9.80E-02 | 9.80E-02 | 9.80E-02 | 9.80E-02 | 9.80E-02 |
| kvc/kvo - Table 15-2* | dimensionless | 5.20E-01 | 5.70E-01 | 7.70E-01 | 8.60E-01 | 5.70E-01 |
| *DCE&VC from Hennet | | | | | | |
| **Hadnot Point** | | | | | | |
| Raw Water (0.8MG, Q=5MGD) | | | | | | |
| Residence time | Hour | 3.84E+00 | 3.84E+00 | 3.84E+00 | 3.84E+00 | 3.84E+00 |
| **(kv)env - Table 15-3, low calculated** | **1/hour** | **8.00E-03** | **8.00E-03** | **8.00E-03** | **8.00E-03** | **8.00E-03** |
| (Kcx)env - Eq 15-22 | 1/hour | 2.81E-03 | 3.25E-03 | 5.27E-03 | 6.28E-03 | 3.25E-03 |
| C/Co - Eq 15-11 | dimensionless | 9.89E-01 | 9.88E-01 | 9.80E-01 | 9.76E-01 | 9.88E-01 |
| **R = (1-C/Co)*100** | **%** | **1.07** | **1.24** | **2.00** | **2.38** | **1.24** |
| **(kv)env - Table 15-3, low literature** | **1/hour** | **4.80E-03** | **4.80E-03** | **4.80E-03** | **4.80E-03** | **4.80E-03** |
| (Kcx)env - Eq 15-22 | 1/hour | 1.69E-03 | 1.95E-03 | 3.16E-03 | 3.77E-03 | 1.95E-03 |
| C/Co - Eq 15-11 | dimensionless | 9.94E-01 | 9.93E-01 | 9.88E-01 | 9.86E-01 | 9.93E-01 |
| **R = (1-C/Co)*100** | **%** | **0.65** | **0.75** | **1.21** | **1.44** | **0.75** |
| Clearwell (2.5 MG, Q=5MGD) | | | | | | |
| Residence time | Hour | 1.20E+01 | 1.20E+01 | 1.20E+01 | 1.20E+01 | 1.20E+01 |
| **(kv)env - Table 15-3, low calculated** | **1/hour** | **8.00E-03** | **8.00E-03** | **8.00E-03** | **8.00E-03** | **8.00E-03** |
| (Kcx)env - Eq 15-22 | 1/hour | 2.81E-03 | 3.25E-03 | 5.27E-03 | 6.28E-03 | 3.25E-03 |
| C/Co - Eq 15-11 | dimensionless | 9.67E-01 | 9.62E-01 | 9.39E-01 | 9.27E-01 | 9.62E-01 |
| **R = (1-C/Co)*100** | **%** | **3.32** | **3.83** | **6.12** | **7.26** | **3.83** |
| **(kv)env - Table 15-3, low literature** | **1/hour** | **4.80E-03** | **4.80E-03** | **4.80E-03** | **4.80E-03** | **4.80E-03** |
| (Kcx)env - Eq 15-22 | 1/hour | 1.69E-03 | 1.95E-03 | 3.16E-03 | 3.77E-03 | 1.95E-03 |
| C/Co - Eq 15-11 | dimensionless | 9.80E-01 | 9.77E-01 | 9.63E-01 | 9.56E-01 | 9.77E-01 |
| **R = (1-C/Co)*100** | **%** | **2.00** | **2.32** | **3.72** | **4.42** | **2.32** |
| Water Tower (0.3 MG, Q=1.25MGD) | | | | | | |
| Residence time | Hour | 5.76E+00 | 5.76E+00 | 5.76E+00 | 5.76E+00 | 5.76E+00 |
| **(kv)env - Table 15-3, low calculated** | **1/hour** | **8.00E-03** | **8.00E-03** | **8.00E-03** | **8.00E-03** | **8.00E-03** |
| (Kcx)env - Eq 15-22 | 1/hour | 2.81E-03 | 3.25E-03 | 5.27E-03 | 6.28E-03 | 3.25E-03 |
| C/Co - Eq 15-11 | dimensionless | 9.84E-01 | 9.81E-01 | 9.70E-01 | 9.64E-01 | 9.81E-01 |
| **R = (1-C/Co)*100** | **%** | **1.61** | **1.86** | **2.99** | **3.56** | **1.86** |
| **(kv)env - Table 15-3, low literature** | **1/hour** | **4.80E-03** | **4.80E-03** | **4.80E-03** | **4.80E-03** | **4.80E-03** |
| (Kcx)env - Eq 15-22 | 1/hour | 1.69E-03 | 1.95E-03 | 3.16E-03 | 3.77E-03 | 1.95E-03 |
| C/Co - Eq 15-11 | dimensionless | 9.90E-01 | 9.89E-01 | 9.82E-01 | 9.79E-01 | 9.89E-01 |
| **R = (1-C/Co)*100** | **%** | **0.97** | **1.12** | **1.80** | **2.15** | **1.12** |

| Tanks - Thomas/Smith Approach - Tarawa Terrace | | | | | | |
|---|---|---|---|---|---|---|
| Chemical Properties | | PCE | TCE | 1,2tDCE | VC | Bz |
| | | | | | | |
| H | atm-m3/mol) | 1.31E-02 | 7.07E-03 | 7.42E-03 | 2.17E-02 | 4.36E-03 |
| R | tm-m2/(mol-K) | 8.21E-05 | 8.21E-05 | 8.21E-05 | 8.21E-05 | 8.21E-05 |
| T | K | 2.93E+02 | 2.93E+02 | 2.93E+02 | 2.93E+02 | 2.93E+02 |
| H' | dimensionless | 5.44E-01 | 2.94E-01 | 3.08E-01 | 9.02E-01 | 1.81E-01 |
| Dw | cm2/s | 7.59E-06 | 8.43E-06 | 1.17E-05 | 1.38E-05 | 8.99E-06 |
| Da | cm2/s | 8.13E-02 | 8.90E-02 | 8.65E-02 | 1.03E-01 | 9.80E-02 |
| MW | g/mol | 1.66E+02 | 1.31E+02 | 96.90 | 6.25E+01 | 7.81E+01 |
| (D)O2,w | cm2/s | 8.99E-06 | 8.99E-06 | 8.99E-06 | 8.99E-06 | 8.99E-06 |
| (D)O2,a | cm2/s | 9.80E-02 | 9.80E-02 | 9.80E-02 | 9.80E-02 | 9.80E-02 |
| kvc/kvo - Table 15-2* | dimensionless | 5.20E-01 | 5.70E-01 | 7.70E-01 | 8.60E-01 | 5.70E-01 |
| *DCE&VC from Hennet | | | | | | |
| | | | | | | |
| **Tarawa Terrace** | | | | | | |
| | | | | | | |
| Clearwell (0.5 MG, Q= 1 MGD) | | | | | | |
| Residence time | Hour | 1.80E+01 | 1.80E+01 | 1.80E+01 | 1.80E+01 | 1.80E+01 |
| | | | | | | |
| **(kv)env - Table 15-3, low calculated** | **1/hour** | **8.00E-03** | **8.00E-03** | **8.00E-03** | **8.00E-03** | **8.00E-03** |
| (Kcx)env - Eq 15-22 | 1/hour | 2.81E-03 | 3.25E-03 | 5.27E-03 | 6.28E-03 | 3.25E-03 |
| C/Co - Eq 15-11 | dimensionless | 9.51E-01 | 9.43E-01 | 9.10E-01 | 8.93E-01 | 9.43E-01 |
| **R = (1-C/Co)*100** | **%** | **4.93** | **5.69** | **9.04** | **10.70** | **5.69** |
| | | | | | | |
| **(kv)env - Table 15-3, low literature** | **1/hour** | **4.80E-03** | **4.80E-03** | **4.80E-03** | **4.80E-03** | **4.80E-03** |
| (Kcx)env - Eq 15-22 | 1/hour | 1.69E-03 | 1.95E-03 | 3.16E-03 | 3.77E-03 | 1.95E-03 |
| C/Co - Eq 15-11 | dimensionless | 9.70E-01 | 9.65E-01 | 9.45E-01 | 9.34E-01 | 9.65E-01 |
| **R = (1-C/Co)*100** | **%** | **2.99** | **3.45** | **5.53** | **6.56** | **3.45** |
| | | | | | | |
| Water Tower (0.25 MG, Q=1.MGD) | | | | | | |
| Residence time | Hour | 6.00E+00 | 6.00E+00 | 6.00E+00 | 6.00E+00 | 6.00E+00 |
| | | | | | | |
| **(kv)env - Table 15-3, low calculated** | **1/hour** | **8.00E-03** | **8.00E-03** | **8.00E-03** | **8.00E-03** | **8.00E-03** |
| (Kcx)env - Eq 15-22 | 1/hour | 2.81E-03 | 3.25E-03 | 5.27E-03 | 6.28E-03 | 3.25E-03 |
| C/Co - Eq 15-11 | dimensionless | 9.83E-01 | 9.81E-01 | 9.69E-01 | 9.63E-01 | 9.81E-01 |
| **R = (1-C/Co)*100** | **%** | **1.67** | **1.93** | **3.11** | **3.70** | **1.93** |
| | | | | | | |
| **(kv)env - Table 15-3, low literature** | **1/hour** | **4.80E-03** | **4.80E-03** | **4.80E-03** | **4.80E-03** | **4.80E-03** |
| (Kcx)env - Eq 15-22 | 1/hour | 1.69E-03 | 1.95E-03 | 3.16E-03 | 3.77E-03 | 1.95E-03 |
| C/Co - Eq 15-11 | dimensionless | 9.90E-01 | 9.88E-01 | 9.81E-01 | 9.78E-01 | 9.88E-01 |
| **R = (1-C/Co)*100** | **%** | **1.01** | **1.16** | **1.88** | **2.24** | **1.16** |

**Exhibit C.3**

**Calculations for Equilibrium VOC Losses in Half-filled water buffalo tank**

| **Equilibrium Partitioning Between Liquid (Water) and Gas Phase** | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | PCE | | | TCE | | | 1,2tDCE | | | VC | | | Bz | | |
| | | | | | | | | | | | | | | | | |
| Dl | m2/s | 7.59E-10 | | | 8.43E-10 | | | 1.17E-09 | | | 1.38E-09 | | | 8.99E-10 | | |
| Dg | m2/s | 8.13E-06 | | | 8.90E-06 | | | 8.65E-06 | | | 1.03E-05 | | | 9.82E-06 | | |
| R | atm-m2/(mol-K) | 8.21E-05 | | | 8.21E-05 | | | 8.21E-05 | | | 8.21E-05 | | | 8.21E-05 | | |
| T | K | 2.93E+02 | | | 2.93E+02 | | | 2.93E+02 | | | 2.93E+02 | | | 2.93E+02 | | |
| H | atm-m3/mol) | 1.31E-02 | | | 7.07E-03 | | | 7.42E-03 | | | 2.17E-02 | | | 4.36E-03 | | |
| H' | dimensionless | 5.44E-01 | | | 2.94E-01 | | | 3.08E-01 | | | 9.02E-01 | | | 1.81E-01 | | |
| | | | | | | | | | | | | | | | | |
| Equilibrium Calcs for tank | Co = | 1.00E+02 | | mg/m^3 | | | | | | | | | | | | |
| Tank Fullness | | | | | | | | | | | | | | | | |
| Frac Full | Vg/Vw | fw | Cw | R (%) | fw | Cw | R (%) | fw | Cw | R (%) | fw | Cw | R (%) | fw | Cw | R (%) |
| 0.50 | 1.00E+00 | 6.48E-01 | 64.75 | 35.25 | 7.73E-01 | 77.29 | 22.71 | 7.64E-01 | 76.44 | 23.56 | 5.26E-01 | 52.59 | 47.41 | 8.47E-01 | 84.66 | 15.34 |

Schwarzenbach et al. 1993; Schwarzenbach et al., 1995

fw = mass in aqueous phase / total mass

fw = {(CwVw)/(CwVw+CaVa)} = {1/(1+(CaVa/(CwVw))} = (1/(1+Kh'(Va/Vw))}

Cw = fw *Mtot/Vw = fw * (Co*Vw)/Vw = fw * Co

R = {(Co - Cw)/Co}*100

**Exhibit C.4**

**Thompson/Smith calculations for 6 hour losses (mid-point time of 12 hours shift) in water buffaloes**

| **Tanks - Thomas/Smith Approach - Water Buffaloes** | | | | | | |
|---|---|---|---|---|---|---|
| Chemical Properties | | PCE | TCE | 1,2tDCE | VC | Bz |
| | | | | | | |
| H | atm-m3/mol) | 1.31E-02 | 7.07E-03 | 7.42E-03 | 2.17E-02 | 4.36E-03 |
| R | tm-m2/(mol-K) | 8.21E-05 | 8.21E-05 | 8.21E-05 | 8.21E-05 | 8.21E-05 |
| T | K | 2.93E+02 | 2.93E+02 | 2.93E+02 | 2.93E+02 | 2.93E+02 |
| H' | dimensionless | 5.44E-01 | 2.94E-01 | 3.08E-01 | 9.02E-01 | 1.81E-01 |
| Dw | cm2/s | 7.59E-06 | 8.43E-06 | 1.17E-05 | 1.38E-05 | 8.99E-06 |
| Da | cm2/s | 8.13E-02 | 8.90E-02 | 8.65E-02 | 1.03E-01 | 9.80E-02 |
| MW | g/mol | 1.66E+02 | 1.31E+02 | 96.90 | 6.25E+01 | 7.81E+01 |
| (D)O2,w | cm2/s | 8.99E-06 | 8.99E-06 | 8.99E-06 | 8.99E-06 | 8.99E-06 |
| (D)O2,a | cm2/s | 9.80E-02 | 9.80E-02 | 9.80E-02 | 9.80E-02 | 9.80E-02 |
| kvc/kvo - Table 15-2* | dimensionless | 5.20E-01 | 5.70E-01 | 7.70E-01 | 8.60E-01 | 5.70E-01 |
| *DCE&VC from Hennet | | | | | | |
| | | | | | | |
| **Water Buffaloes** | | | | | | |
| | | | | | | |
| Residence time - 6 hrs | Hour | 6.00E+00 | 6.00E+00 | 6.00E+00 | 6.00E+00 | 6.00E+00 |
| | | | | | | |
| **(kv)env - Table 15-3, low literature** | **1/hour** | **4.80E-03** | **4.80E-03** | **4.80E-03** | **4.80E-03** | **4.80E-03** |
| (Kcx)env - Eq 15-22 | 1/hour | 1.69E-03 | 1.95E-03 | 3.16E-03 | 3.77E-03 | 1.95E-03 |
| C/Co - Eq 15-11 | dimensionless | 9.90E-01 | 9.88E-01 | 9.81E-01 | 9.78E-01 | 9.88E-01 |
| **R = (1-C/Co)*100** | **%** | **1.01** | **1.16** | **1.88** | **2.24** | **1.16** |

## APPENDIX A:

## Response to Reports of Remy J.-C. Hennet & Jay Brigham

## Regarding Water Buffaloes

## Introduction

The reports of Remy J.-C. Hennet & Jay Brigham, dated December 9, 2024, discuss the use of water buffaloes at Camp Lejeune. Certain of my calculations set forth in the body of my report depend on the design and configuration of the water buffaloes used at Camp Lejeune, especially as this relates to the filling process. This appendix sets forth my understanding and opinions regarding the models of water buffaloes used from 1953 to 1987 at Camp Lejeune, which forms the basis of certain of my calculations. Based on my review of historical documentation, as discussed below, I disagree in part with Drs. Hennet and Brigham regarding how water buffaloes were filled at Camp Lejeune over time.

## Response regarding Water Buffalo "Filling"

Dr. Hennet opines that:

> *"In summary. A substantial portion of COCs that may have been present in the treated water used to fill a water buffalo would have unavoidably been lost to evaporation during filling, use, and variations of temperature. These COC reductions between the raw water and the water in the water buffaloes would have been in the order of 52% to 73% based on my estimation." (pg. 5-43)*

Of the three potential causes of VOC reductions, Dr. Hennet claims the majority of the loss is attributed to the presumed historical "filling" of the tank:

> *"The COC reductions in the water filled and stored in the water buffaloes can be estimated. The largest COC mass removal from the water is during fill-up of the tank when conditions are ripe for volatilization, through increased contact between water and air due to the forcing of water through a strainer that generates water jets and droplets that greatly increase the surface area of the water/air interface for COC exchange to the tank air. The air containing COCs is expelled from the tank during filling. The filling of the tank through a strainer would involve spraying, splashing, and turbulent flow." (pg. 5-40)*

> *"These loss rates likely apply during the first half of the tank filling process because the filling strainer extends about halfway down into the tank. For the second half of the filling process, it is assumed that the loss rate declines linearly until the tank is completely full. Considering this decrease in loss rate as the tank fills results in an overall loss rate estimate of about 44% for TCE." (pg. 5-40)*

In making these claims, Dr. Hennet assumed:

1. All of the water buffaloes in use from August 1st 1953 to December 31st 1987 were equipped with a *"filling port on the water tank contain[ing] a strainer screen."*
2. That all the water buffaloes were filled through the filling port.

A review of the history of the water buffalo and specifically its use at Camp Lejeune demonstrates that these assumptions are incorrect.

**Chronological Listing of Water Buffaloes – 1943 to 1991**

The WWII era water buffalo was known as a "250-gallon Tank Trailer" or a "1-Ton, 2-Wheel Water Trailer". (TM9-833 Army Technical Manual, BRIGHAM_USA_0000043022). The unit is shown in Figure 1 below.

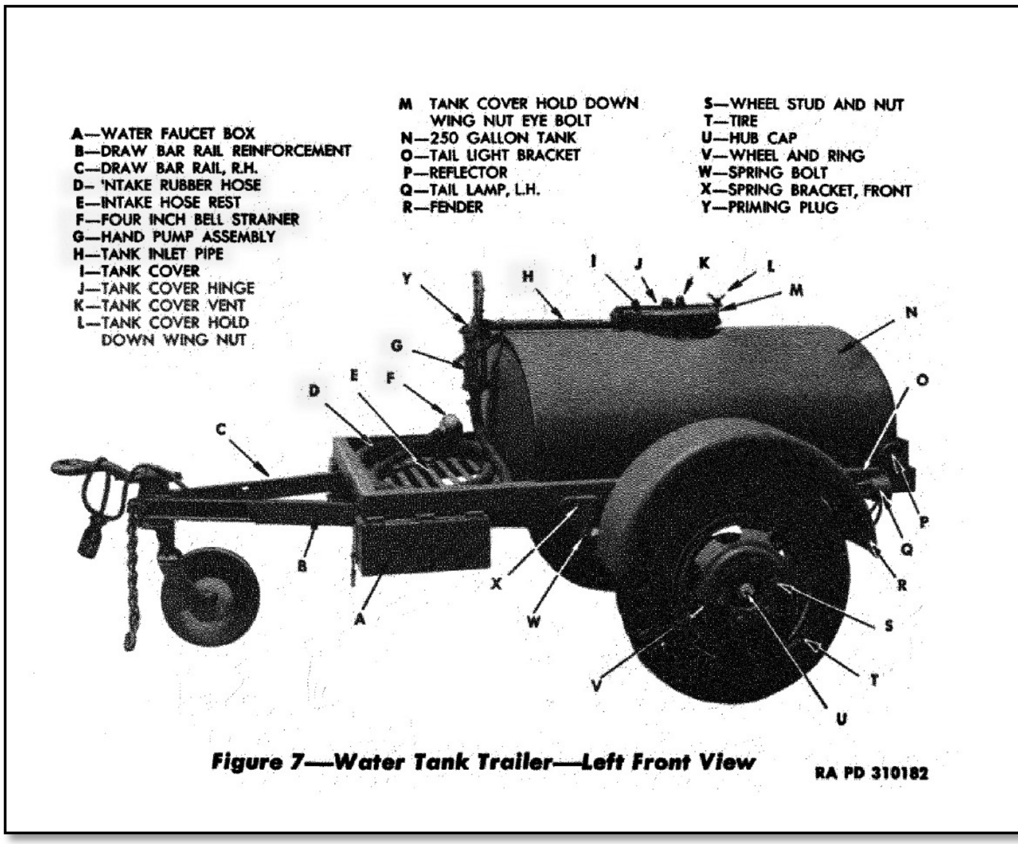



Figure 1 – WWII Water Buffalo. TM9-833 Army Technical Manual, BRIGHAM_USA_0000043035.

This model water buffalo was equipped with a hand pump, intake hose and bell strainer to allow filling the unit in the field from sources such as ponds or streams. In those cases, the bell strainer would be placed in the water source, the pump handle would be pumped and the water would flow from the source, through the bell strainer, rubber hose, pump and

then to part “H”, the tank inlet pipe, which dumps the water into the tank at the manhole cover.

In the manual for the WWII era water buffalo (TM9-833 Army Technical Manual, BRIGHAM_USA_0000043022), users are instructed to:

> (1) **WATER TRAILER.** On the water trailer, the manhole cover should be kept closed and held down tightly with the wing nut, except when tank is being filled through this cover. The cover on the bell strainer at the end of the intake hose should be kept closed, except when filling the tank with the hand pump. The water faucet box covers should be kept closed and locked with snap, except when drawing water from the faucets.

BRIGHAM_USA_0000043040.

On this model, which is not equipped with a fill hatch like what is described in Dr. Hennet’s report, the filling of the tank is accomplished through the manhole cover, which as the name describes is a man-sized hatch in the top of the tank that allows filling, inspection and cleaning of the tank. There is no strainer involved in the process.

Chronologically the next version of the water buffalo was designated the M106. The M106 was very similar to its predecessor with two notable exceptions. The first is its capacity was increased to 400 gallons. The second is the addition of a filler hatch assembly located at the top of the tank near the front as shown in Figure 2. (TM9-875B Army Technical Manual (Oct. 1951)).

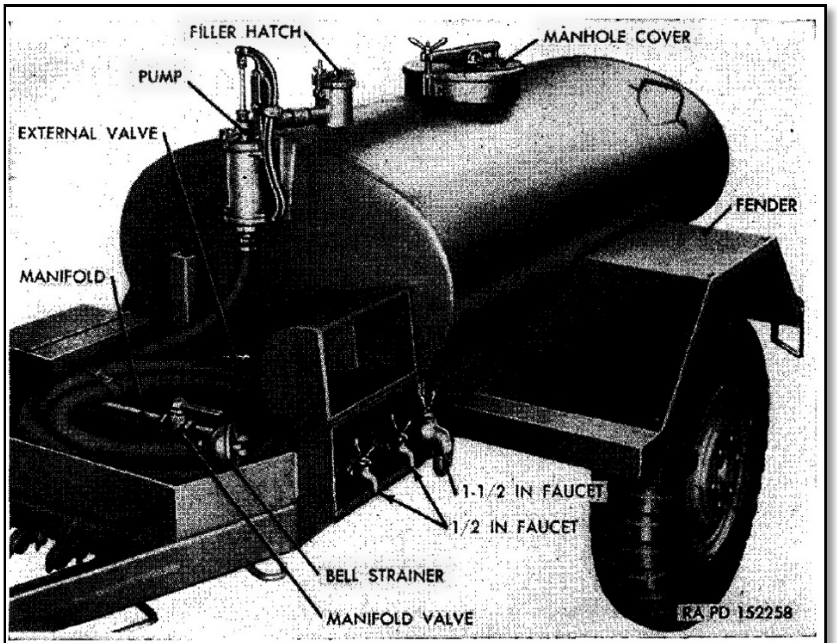



*Figure 8. Water tank equipment of water tank trailer M106.*

Figure 2 – M106 Water Buffalo. TM9-875B Army Technical Manual (Oct. 1951), p. 9.

The addition of the filler hatch assembly changed the water path from the pump. Instead of exiting into the tank at the manhole cover, the water from the pump now travels to the filler hatch. The M106 has a strainer in the neck of the filler hatch (See Figure 3) which is equipped with a fine mesh screen that removes particulate matter from the incoming water.

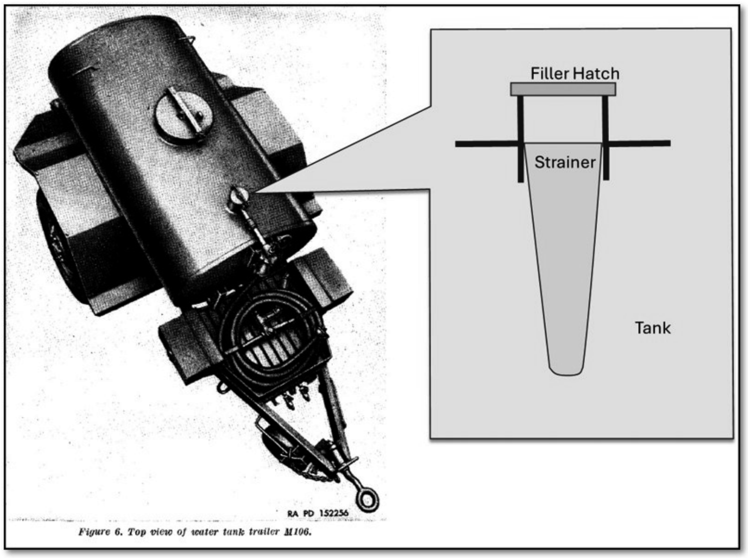
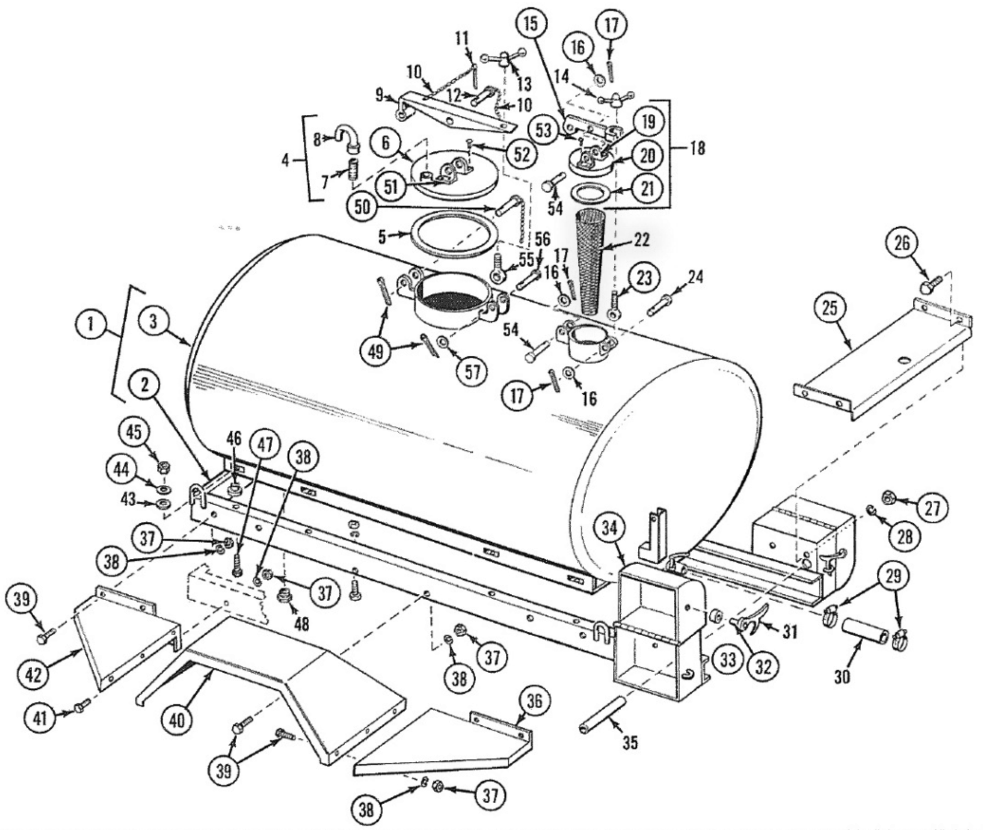



Figure 3 – M106 Strainer (TM9-875B Army Technical Manual (Oct. 1951), p. 7)

The addition of the strainer is especially important when the water supply is a pond, stream or other similar source, but it provides no benefit when being filled with finished water from a water distribution system such as the Hadnot Point WTP. An exploded view of the filler hatch and strainer is shown in Figure 4 below.




| (1) ILLUST (a) FIG NO | (1) ILLUST (b) ITEM NO | (2) SOURCE, MAINT AND RECOVERABILITY CODE (a) MATERIEL CODE | (2) (b) SOURCE | (2) (c) MAINTENANCE LEVEL | (2) (d) RECOVERABILITY | (3) FEDERAL STOCK NO | (4) DESCRIPTION | (5) UNIT OF ISSUE | (6) QTY INC IN UNIT | (7) 15-DAY MAINTENANCE ALLOWANCE PER 100 EQUIPMENTS (a) CO OR BTRY | (7) (b) SEP CO SEP BN OR REGT | (7) (c) 3RD ECH (DIR SUP) | (7) (d) 4TH ECH (GEN SUP) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | WATER TANK, TANK FRAME, AND RELATED PARTS - (M106A1, M107A1, M107A2, and M107A2C) (Fig. 133) | | | | | | |
| 133 | 22 | | P | O | | 4730-546-5898 | STRAINER ELEMENT, SEDIMENT: (8735825) | ea | 1 | | | | |

FIGURE 4 – M107A1 Strainer Shown, M106 is the same (TM 9-2330-213-14 Army Technical Manual (1964), BRIGHAM_USA_0000041587).

The service maintenance manual for the M106 includes this description of the loading of the water tank:

## Section III. OPERATION OF REGULAR EQUIPMENT OF WATER TANK TRAILER M106

### 32. Loading and Unloading Water Tank

*a.* CHECK CONDITION OF TANK BEFORE LOADING. Unlatch manhole cover (fig. 8), raise cover, and check to determine if tank is in proper condition to receive and transport water for purpose intended. Clean tank and flush tank, valves, piping, and faucets, if tactical situation permits.

*Note.* Highest sanitary conditions must be preserved in handling water for drinking purposes.

*b.* LOADING TANK FROM OVERHEAD, FREE-FLOWING SOURCE. Unlatch filler hatch cover, raise cover, and check to determine if sleeve strainer is in place and is clean. Direct flow of water into filler hatch (fig. 8). Capacity of tank is 400 gallons. When filled, latch filler hatch cover.

*c.* LOADING TANK FROM SOURCE FROM WHICH WATER MUST BE PUMPED. Position trailer adjacent to water supply on ground as solid as possible.

*Note.* Weight of trailer will increase approximately 3,300 pounds when filled.

Unfasten bell strainer and hose assembly (fig. 8), turn wing nut to open bell strainer, and place bell strainer in water source. Prime pump by unscrewing priming plug and filling cylinder above plunger assembly with clean water. Operate handle up and down until tank is filled.

Figure 5 – M106 Filling. TM9-875B Army Technical Manual (Oct. 1951), p.43.

The M106 was the first water buffalo to utilize the filler hatch and strainer screen. The fill point moved from the manhole cover to the filler hatch with the introduction of this modelwhen using an “Overhead Free-Flowing source”.

The M107 was the next iteration of the water buffalo. The major change was the removal of the hand pump and associated components (Figure 6) (TM 9-2330-213-14 Army Technical Manual (Jan. 1964), BRIGHAM_USA_0000041587). All other aspects of the M106 and M107 remain the same.

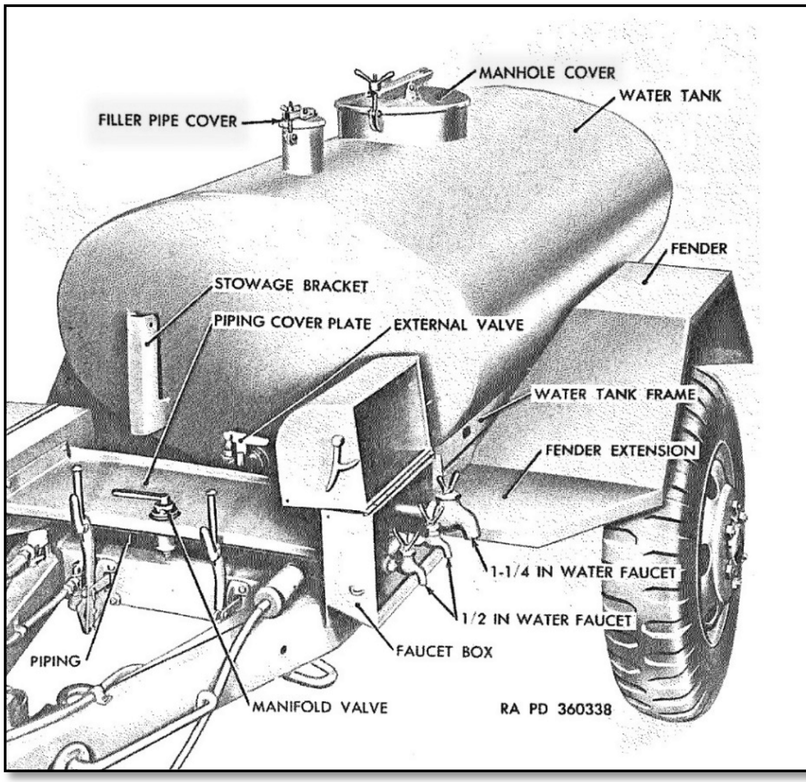



Figure 6 – M107A1. BRIGHAM_USA_0000041599.

Filling the M107A1 is still directed to be done through the filler hatch as described in Figure 7 below.

d. Loading the Water Tank.

(1) Open manhole cover and make sure tank is clean. Flush tank, valves, piping, and faucets if tactical situation permits.

Note. Fill the tank through the filler pipe.

(2) All water tank trailers may be filled from an overhead, free flowing source.

Warning: Highest sanitary practices must be exercised in handling water for drinking purposes.

(3) Open filler pipe cover and make sure the strainer is in place and clean. When filled, latch the filler pipe cover. Tank capacity is 400 gallons.

Figure 7 – M107A1 filling. BRIGHAM_USA_0000041622)

Nineteen sixty-four saw the introduction of the M149. The first version of the M149 can be identified by its unique tank shape as shown in Figures 8 & 9 below (TM 9-2330-267-14 Army Technical Manual (Oct 1964), BRIGHAM_USA_0000041997). Other than the tank shape the M149 is essentially the same as the M107 including the 400-gallon capacity and use of a filler hatch and a strainer.

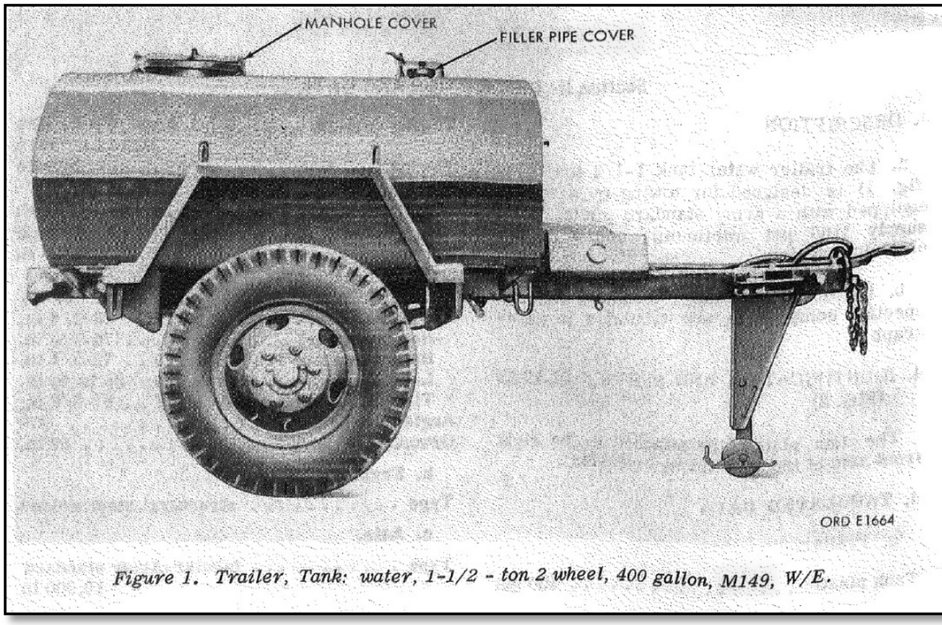



Figure 8 – M149. BRIGHAM_USA_0000042006.

Figure 9 – M149 Tank Shape (https://www.ebay.com/itm/223995969791)

The next generation of the M149, designated the M149A1 is identical to the M149 with the notable exception that the filler hatch was discontinued. The illustration below (Figure 10) is from the TM9-2330-267-14 Army Technical Manual (June 1971). It shows both the M149 (top) and its replacement, the M149A1 (bottom).

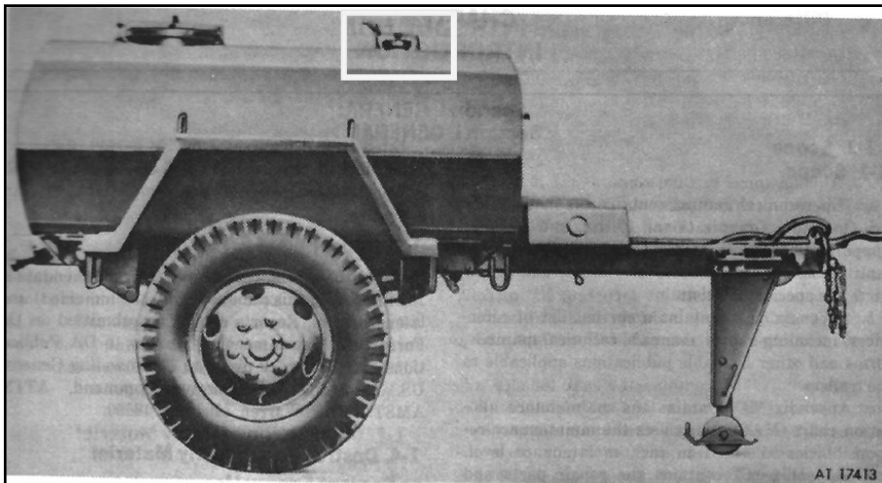



*Figure 1-1. Trailer, Tank water, 400 gallon, 1½ ton, 2-wheel, right side view of the M149.*

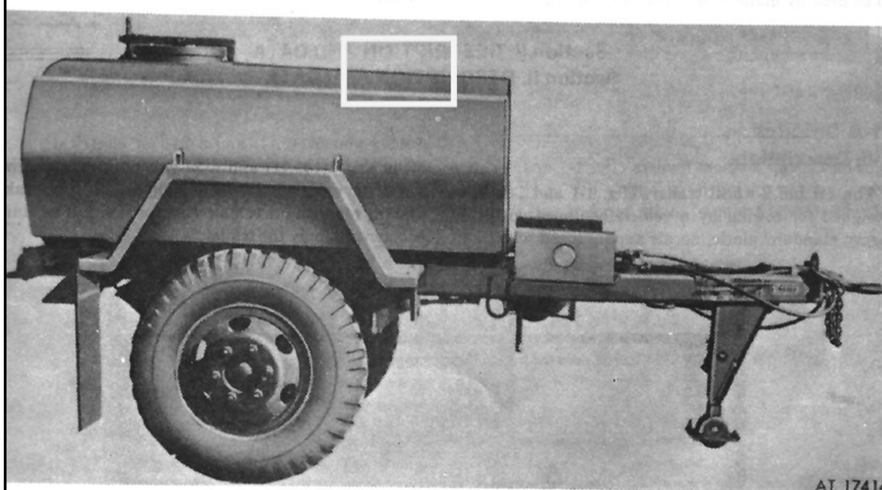



*Figure 1-2. Trailer, Tank: water, 400 gallon, 1½ ton, 2-wheel, right side view of the M149A1 and M625.*

Figure 10 – M149 and M149A1 (TM9-2330-267-14 Army Technical Manual, p. 1-2)

The earliest M149A1 identified was manufactured in January 1968. The photos in Figure 11 show the lack of a filler hatch.


Figure 11 – M149A1: No filler hatch (https://www.bigiron.com/Lots/1968Army400-Gal2-WheelM149TankTrailer)

This design change represents a significant shift in the water buffalo filling methodology as there is only one way to fill the tank – through the manhole cover.

This change in methodology was further demonstrated when the Army issued Change No. 3 for the M149 & M149A1 in December of 1968 (BRIGHAM_USA_0000041969), which consisted of 28 pages with the instructions to "Remove old pages and insert new pages as indicated below." On page 1, Chapter 1 Introduction, Section II. Description and Data there is a note. The note states (Figure 12):

**Section II. DESCRIPTION AND DATA**

**3. Description**

*a*. The trailers, water tank, 1½-ton, M149 and M149A1 (fig. 1) are designed for towing by a vehicle equipped with an Army standard pintle, an air supply (100 psi minimum), and a 24-volt electrical system.

*b*. The trailer, water tank, 1½-ton, M625, is designed for towing by a vehicle equipped with an Army standard pintle, an air supply (vacuum) for the operation of a hydrovac brake system and a 12-volt electrical system.

*a. Trailer*

*Note*. Some trailers are not equipped with a tank strainer assembly. A defective assembly will be removed but not replaced.

Tank, plastic............400 gal
Towing vehicle
(M149, M149A1)..........2½–Ton, 6X6, M35, M35A1, M211
(M625)..................2½–Ton, 6X6, M602
Towing facilities...........lunette
Maximum towing speed:
Highway...............50 mph
Cross-country..........25 mph

Figure 12 – 1968, Strainer note. TM 9-2330-267-14 C3 (Dec. 1968), BRIGHAM_USA_0000041973.

This note is not found in the original M149 Manual issued in 1964 as shown below in Figure 13:

**Section II. DESCRIPTION AND DATA**

3. DESCRIPTION

a. The trailer water tank 1-1/2 ton, M149 (fig. 1) is designed for towing by a vehicle equipped with a army standard pintle, an air supply (100 psi minimum), and a 24-volt electrical system.

b. Performance details, technical data and specific components are tabulated in paragraph 5.

4. IDENTIFICATION AND SERVICE PLATES

| | |
|---|---|
| Towing vehicle | 2-1/2 ton, 6 x 6, M35 M35A1,& M211 |
| Towing facilities | lunette |
| Maximum towing speed: | |
| Highway | 50 mph |
| Cross-country | 25 mph |
| Net weight | 2500 lb |
| Overall dimensions: | |
| Length | 83 in. |
| Width | 82-1/4 in. |
| Height (empty) | 76-1/2 in. |
| Height (loaded) | 72-3/4 in. |
| Lunette height | 36 to 40 in. |

Figure 13 – 1964 version, no note. TM 9-2330-267-14 Army Technical Manual (1964), BRIGHAM_USA_0000042005.

The significance of this note is that as early as December 1968 the army is acknowledging that the M149A1 was not equipped with a strainer, and the use of the strainer became optional for the M149 in cases where the strainer was damaged or found defective.

In 1970 the M149A1 underwent a tank design change. The M149 went from the non-oval, non-round tank shape shown in the top of Figure 14 below to a round tank shape as shown in the bottom of Figure 14. Again, note no filler hatch on the M149A1.

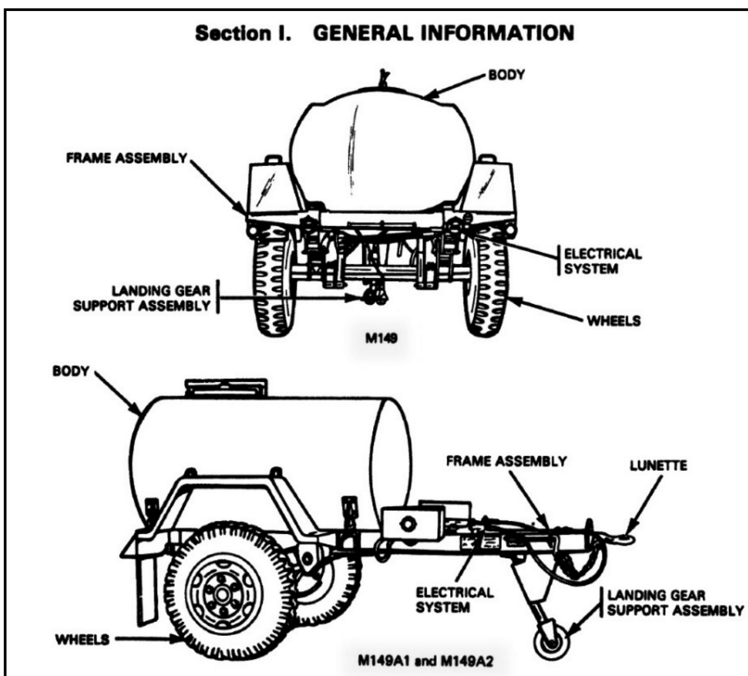


Figure 14 – M149 (top), M149A1 & M149A2 (TM9-2330-267-14P Army Technical Manual (1981), BRIGHAM_USA_0000043121)

Again, with the discontinuation of the filler hatch there is only one method available to fill the M149A1 water buffalo – through the manhole cover.

**Generational Changes to M107 Technical Manual and Tank Filling Process**

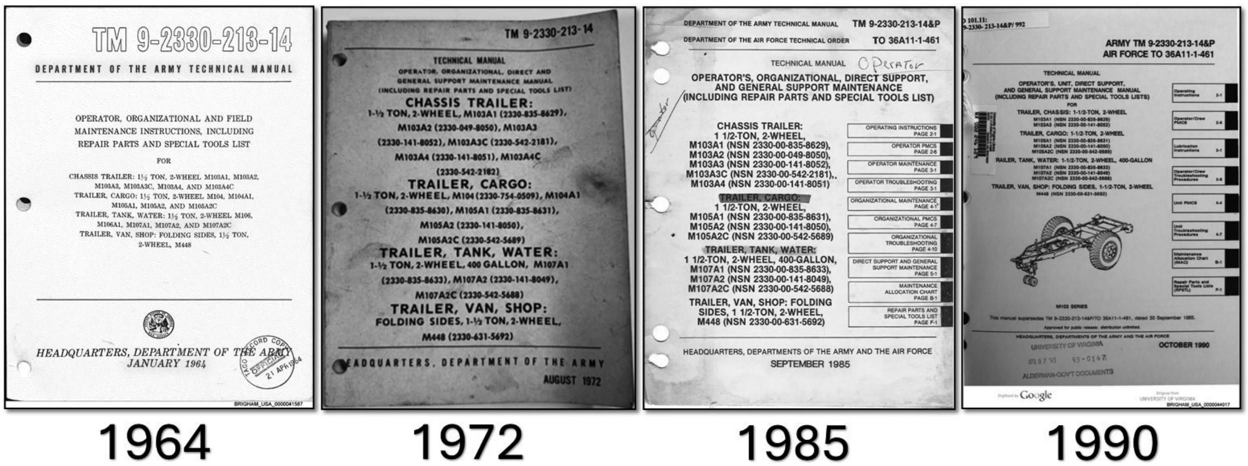



Figure 15 – M107 Technical Manuals 1964 to 1990

The Army periodically published updated manuals for the various pieces of equipment it oversees (Figure 15). The M107 has had 3 such updates since 1964. Of interest is that the process of filling the water buffalo changed dramatically from 1964 to 1990. The filling process outlined in the 1964 edition is shown below (Figure 16).

d. Loading the Water Tank.

(1) Open manhole cover and make sure tank is clean. Flush tank, valves, piping, and faucets if tactical situation permits.

Note. Fill the tank through the filler pipe.

(2) All water tank trailers may be filled from an overhead, free flowing source.

Warning: Highest sanitary practices must be exercised in handling water for drinking purposes.

(3) Open filler pipe cover and make sure the strainer is in place and clean. When filled, latch the filler pipe cover. Tank capacity is 400 gallons.

Figure 16 – 1964 M107A1 Fill Process. TM 9-2330-213-14 Army Technical Manual (1964), BRIGHAM_USA_0000041622.

In the August 1972 edition, which supersedes the October 1964 edition shown above, the fill process switches from being done through the filler hatch to the manhole cover as described in the text below (Figure 17). The change in instructions also clarified a phrase used in earlier manuals that will be discussed below.

c. *Faucets* (fig. 1-3). The water faucet handles are squeezed together to release water from the faucets.

d. *Loading the Water Tank.*

(1) Open manhole cover and make sure tank is clean. Flush tank, valves, piping, and faucets if tactical situation permits.

(2) All water tank trailers may be filled from an overhead, free flowing source, or by pressure pump. Use manhole opening for refill operation.

**WARNING**

Highest sanitary practices must be exer-

Figure 17 – August 1972 M107 Fill Process. TM 9-2330-213-14 Army Technical Manual (1972)

As called out in the “Loading the Water Tank” instructions, “Use manhole opening for refill operation”  (Figure 17).

The phrase of interest in the filling instructions which was used in several earlier water buffalo technical manuals is “free-flowing source.” A free-flowing source implies gravity fed, which suggests the fill hatch was never intended to be filled with a high-pressure-high-flow hose that was tapped into the base’s water distribution system. In the 1972 edition, the text specifically calls out that when filling through the manhole cover a pressure pump can be used, which is equivalent to water-flow/pressure like that supplied by the water distribution system.

In 1985 the Army reformatted the tank filling instructions. The 1985 M107 fill instructions are shown in Figure 18 below.

FILLING M107 SERIES WATER TANK TRAILER

**WARNING**

The highest sanitary practices must be exercised in handling water for drinking purposes. Serious illness could result from impure drinking water.

1. Position water tank trailer next to water supply on solid level ground.
2. Open manhole cover (1).
3. All water tank trailers may be filled from an overhead, free-flowing source, or by a pressure pump through manhole opening (2).

DRAWING WATER, M107 SERIES WATER TANK TRAILER

1. Open external valve (3), permitting water to flow from water tank to manifold valve (4) and faucet (5).
2. Open manifold valve (4), permitting water to flow to faucets (6 and 7).
3. Squeeze handles (8) on top of faucets (5, 6, and 7) as required, permitting water to flow.

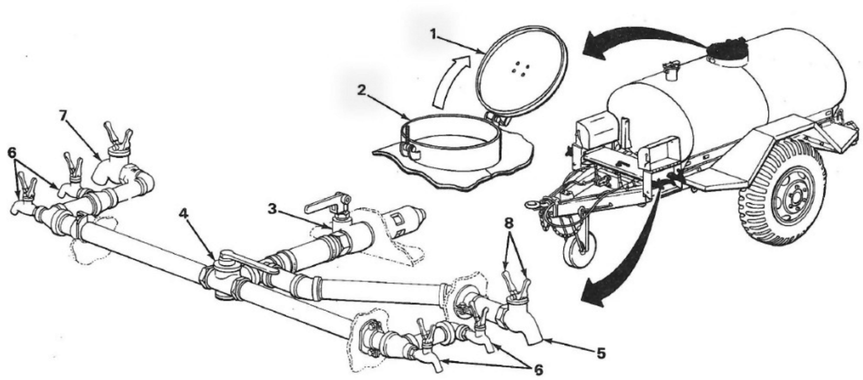
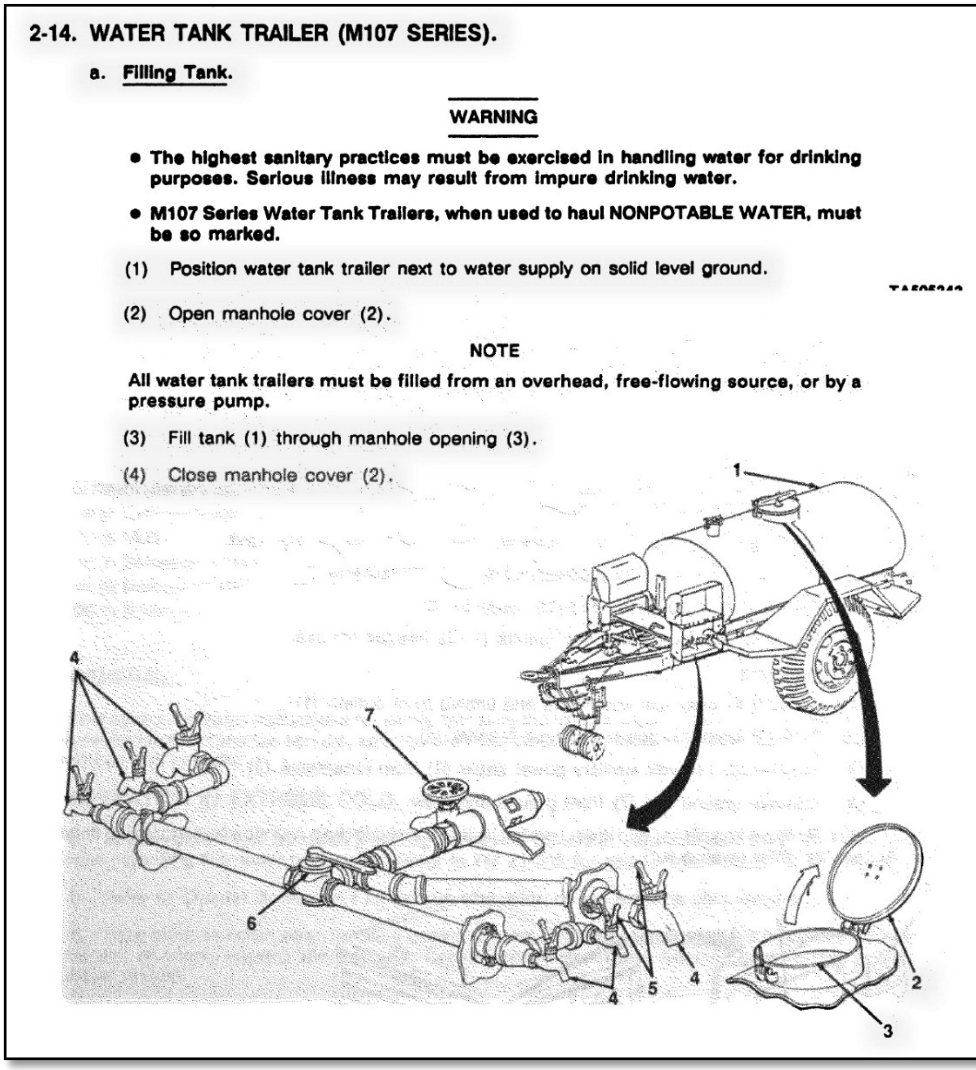



Figure 18 – 1985 M107 Fill Process. TM 9-2330-213-14&P Army Technical Manual (1985).

The fill process stays the same in the 1990 edition as shown in Figure 19 below.



**2-14. WATER TANK TRAILER (M107 SERIES).**

a. Filling Tank.

**WARNING**

- **The highest sanitary practices must be exercised in handling water for drinking purposes. Serious illness may result from impure drinking water.**
- **M107 Series Water Tank Trailers, when used to haul NONPOTABLE WATER, must be so marked.**

(1) Position water tank trailer next to water supply on solid level ground.

(2) Open manhole cover (2).

**NOTE**

**All water tank trailers must be filled from an overhead, free-flowing source, or by a pressure pump.**

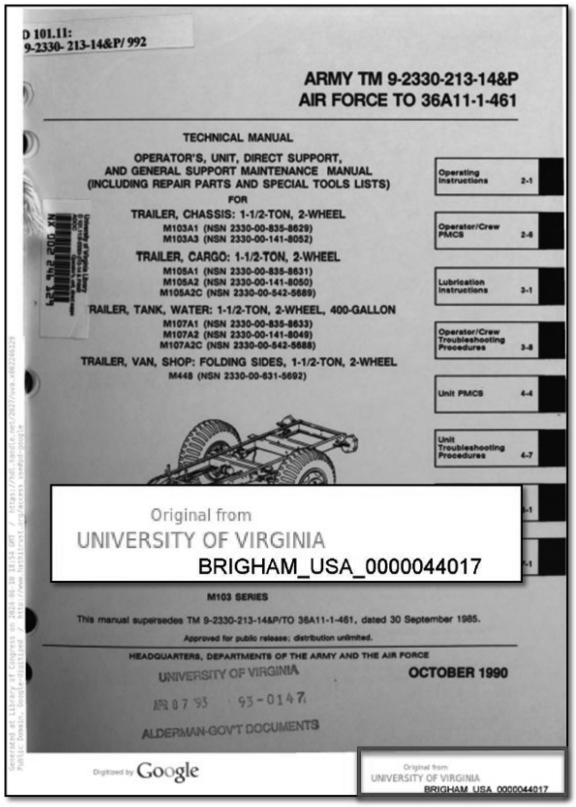
(3) Fill tank (1) through manhole opening (3).

(4) Close manhole cover (2).



Figure 19 – October 1990 M107 Fill Process. TM 9-2330-213-14P Army Technical Manual (1990), BRIGHAM_USA_0000044016.

An important point to be made concerning the October 1990 M107 Technical Manual shown in Figure 19 is that the manual was found in Dr. Brigham's file materials. See Figure 20. The significance of this is that Dr. Brigham's own file materials demonstrate that the filling process had changed from the 1964 manual he relies on for the fill procedure through the strainer. Once he recognized that the process had changed, he should have located sources for earlier editions of the M107 Technical Manual to determine how far back the change took place.



D 101.11:
9-2330-213-14&P/992

ARMY TM 9-2330-213-14&P
AIR FORCE TO 36A11-1-461

TECHNICAL MANUAL

OPERATOR'S, UNIT, DIRECT SUPPORT,
AND GENERAL SUPPORT MAINTENANCE MANUAL
(INCLUDING REPAIR PARTS AND SPECIAL TOOLS LISTS)
FOR
TRAILER, CHASSIS: 1-1/2-TON, 2-WHEEL
M103A1 (NSN 2330-00-835-8629)
M103A3 (NSN 2330-00-141-8052)
TRAILER, CARGO: 1-1/2-TON, 2-WHEEL
M105A1 (NSN 2330-00-835-8631)
M105A2 (NSN 2330-00-141-8050)
M105A2C (NSN 2330-00-542-5689)
TRAILER, TANK, WATER: 1-1/2-TON, 2-WHEEL, 400-GALLON
M107A1 (NSN 2330-00-835-8633)
M107A2 (NSN 2330-00-141-8049)
M107A2C (NSN 2330-00-542-5688)
TRAILER, VAN, SHOP: FOLDING SIDES, 1-1/2-TON, 2-WHEEL
M448 (NSN 2330-00-831-5692)

Operating Instructions 2-1
Operator/Crew PMCS 2-6
Lubrication Instructions 3-1
Operator/Crew Troubleshooting Procedures 3-8
Unit PMCS 4-4
Unit Troubleshooting Procedures 4-7

Original from
UNIVERSITY OF VIRGINIA
BRIGHAM_USA_0000044017

M103 SERIES

This manual supersedes TM 9-2330-213-14&P/TO 36A11-1-461, dated 30 September 1985.
Approved for public release; distribution unlimited.

HEADQUARTERS, DEPARTMENTS OF THE ARMY AND THE AIR FORCE
OCTOBER 1990

UNIVERSITY OF VIRGINIA
APR 07 '93 93-0147
ALDERMAN-GOV'T DOCUMENTS

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Figure 20 – Brigham 1990 M107 Technical Manual, BRIGHAM_USA_0000044017.

Dr. Brigham includes the photograph shown in Figure 21 (image 34) to establish that M107 water buffaloes were in use at least up to January 1977, and he even calls out the oval tank to identify the unit as a M107. What he and Dr. Hennet do not disclose in their reports, nor include in Hennet's COC loss analysis, is that the fill procedure for this and all other M107's at Camp Lejeune was through the manhole cover since January 1972.

**Image 34**

**Oval-Shaped Water Trailer in the Field, January 27, 1977**[335]

Photo by Sgt. Wesley Goodloe

**ICE WATER** — LCpl. Mark A. Long, a radio operator with Communication Company, H & S Bn., Force Troops-2d FSSG, takes time out for a drink of cold water during "Commex 1-77." The water was supplied by the battalion and the cold by "Mother Nature." Unusually cold weather added new dimensions of training to the exercise not normally encountered here.

Figure 21 – Expert Brigham Image 34

According to an inventory of equipment, in 1968 Camp Lejeune had 84 M107s. (Figure 22)

| 1968 Equipment Inventory | | | |
|---|---|---|---|
| **Unit** | **Model** | **Stock** | **Quantity** |
| Artillery Regiment | M107A2 | Trlr Tank M-107A2 H20 400 | 24 |
| A.T. Battalion | M107 | Trlr Tank M-107 400 Gal | 5 |
| Shore Party Battalion | M107A2 | Trailer Tank Water 400Gal M107A2 | 9 |
| M.T. Battalion | M107 | Trlr Tank M-107 400 Gal | 5 |
| Medical Battalion | M107A2 | Trailer Tank Water 400Gal M107A2 | 9 |
| PFCON Battalion | M107A2 | Trailer Tank Water M107A2 | 3 |
| Headquarters Battalion | M107A2 | Trailer Cargo Water 400Gal M107A2 | 5 |
| 2d Engineer Battalion | M107 | Trlr 400 Gal M-107 (water) | 5 |
| Service Battalion | M107A2 | Trailer Tank Water Gal M107A2 | 19 |
| | | **Total Water Buffalo Inventory** | **84** |

Figure 22 – 1968 Camp Lejeune Water Buffalo Inventory
(Base Master Plan-Approx-1972-00368 (bates CLJA_WATERMODELING_01-0000948169 to CLJA_WATERMODELING_01-0000948933)

By no later than and likely well before 1999, the water buffalo inventory switched to exclusively M149s as depicted in Figure 23 below. According to this document there were 71 M149s.

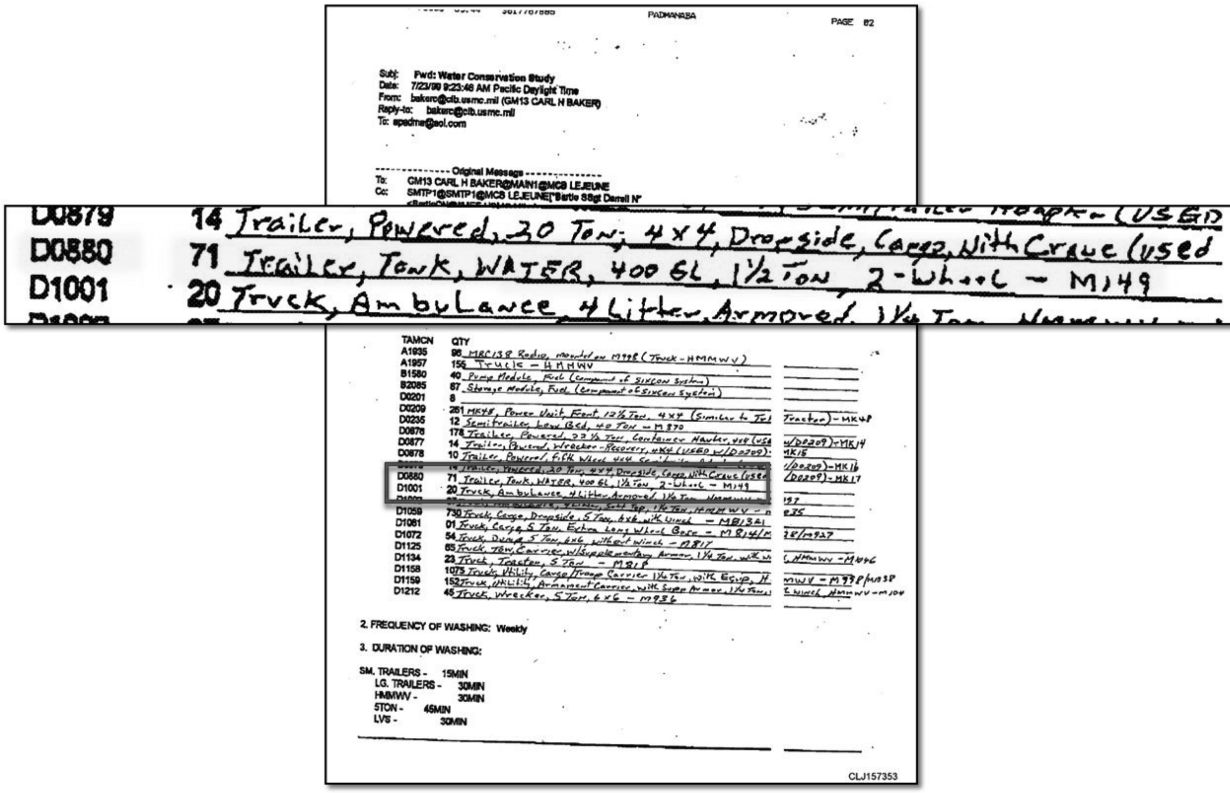


Figure 23 – 1999 Camp Lejeune Water Buffalo Inventory

(CLJ157174.pdf, Bates CLJ157174 to CLJ157472)

This is supported by the affidavit provided by Mr. Mark Cagiano, who was stationed at Camp Lejeune from 1976 to 1980. One of the positions Mr. Cagiano held during this time was Battery Motor Transport Officer. In this position he had the opportunity to observe water buffaloes on a regular basis. According to his affidavit, during his time at Camp Lejeune he observed only one type of water buffalo – the M149A1. This supports that the base was transitioning from the M107 to the M149A1 during the 1970's.Mr. Cagiano stated that he recalled water buffaloes being filled through the manhole from a standpipe,  and on occasion from a fire hydrant.

Regardless of the mix between M107s and M149s, from 1972 to 1987 all water buffaloes would have been filled through the manhole cover based on operating guidance discussed above.

For those M107s earlier than 1972 it is my position that these units more likely than not would have also been filled through the manhole cover. I base this on the following:

1. An affidavit provided by Mr. Ernest Hunt. In his affidavit, Mr. Hunt states that he was in motor transport as a truck driver from 1965 to 1966. On a regular basis he observed the filling of M107 water buffaloes, and all of those he observed were filled through the manhole cover.
2. The filler hatch as outlined in several of the manuals is designated for free-flowing water supplies and in early versions fed by a hand-pump.
3. From at least 1968 to 1972 (and thereafter) there were M149A1 (no filler hatch) water buffaloes in use at Camp Lejeune that could only be filled through the manhole cover, making it difficult to believe Marines would be filling the M107 though the flow-constrained filler neck while using the manhole cover to fill the M149A1.

**Water Buffalo Filling Examples**

Figures 24 to 27 below show M149A1 water buffaloes being filled through the manhole cover. These photos are post-1987, but the process is the same regardless of when it took place.

Figure 24 – Filling M149A1 Water Buffalo[1]

[1] https://www.alamy.com/a-service-members-at-fort-mccoy-wis-for-the-86th-training-divisions-combat-support-training-exercise-cstx-86-18-02-fills-a-water-tank-at-improved-tactical-training-base-liberty-on-


Figure 25 - Filling M149A1 Water Buffalo[2]

Figure 26 – Standpipe Hose[3]

north-post-on-aug-8-2018-the-86th-is-holding-the-exercise-as-part-of-the-us-army-reserve-commanding-generals-combat-support-training-program-thousands-of-service-members-with-the-army-as-well-as-other-military-services-and-foreign-militaries-are-participating-in-the-multinational-exercise-including-canadian-armed-forces-members-cstx-86-18-02-is-the-second-of-two-cstxs-by-the-86th-taking-place-at-fort-m-image218541597.html?imageid=7D23ADD4-DE29-445D-A5B2-5F209B22D886&p=725760&pn=1&searchId=0552ab94b97dc8d1ff6efee3a2cf3201&searchtype=0

[2] https://www.usmilitariaforum.com/forums/uploads/monthly_2024_09/Screenshot2024-09-23at21-01-23WaterWorks.png.a78205954b395f11a15d1e0aadbc071e.png

[3] https://itoldya420.getarchive.net/amp/media/us-marine-corps-lance-cpl-codi-heggemeier-2nd-medical-d523c0

Figure 27 - Filling M149A1 Water Buffalo from hydrant[4]

As seen in Figures 24, 25 & 26, the typical method of filling a water buffalo involves the use of what is known as a standpipe. A standpipe is a structure that allows the fill hose to hang down over the water buffalo. In Figures 24 and 25 the hose hangs just above the manhole cover. The fill hose in Figure 26 is longer and can be lowered into the water buffalo tank through the manhole cover. While not shown in the photo, Figure 27 shows filling a water buffalo with a fire hydrant.

**Water Buffalo Tank Fill Time**

Based on standpipe filling and using an online video that captures the entire fill process of an M149A2 water tank,  it was possible to quantify the fill time for a 400-gallon buffalo tank regardless of the model of water buffalo. . Figures 28, 29, 30, 31 & 32 are frames from the video at the zero, one-quarter, one-half, three-quarters and full points. The filling of the 400-gallon tank took just over 2 minutes as demonstrated by the video, which equates to an average flowrate of 200 gpm. (https://www.youtube.com/watch?v=2juC4Ry9hS4&ab_channel=axeandsmash48g).

[4] https://www.nationalguard.mil/Resources/Image-Gallery/News-Images/igphoto/2000709524/

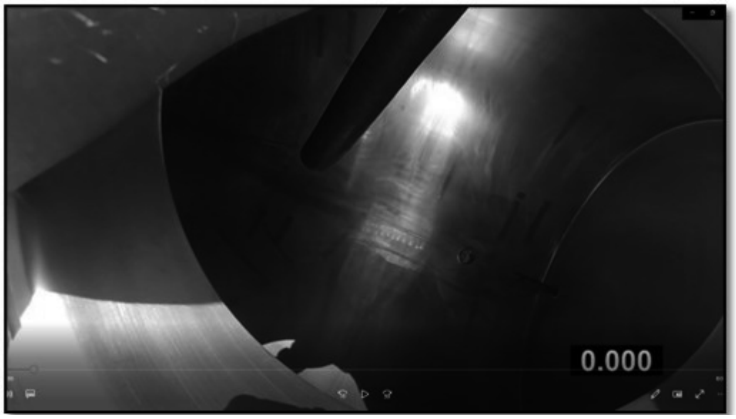


Figure 28 – 0 Full (T=0.0)

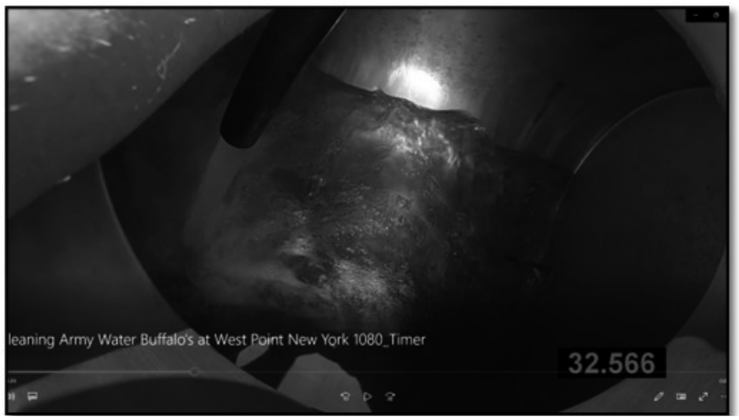


Figure 29 – ¼ Full (T=32.5)

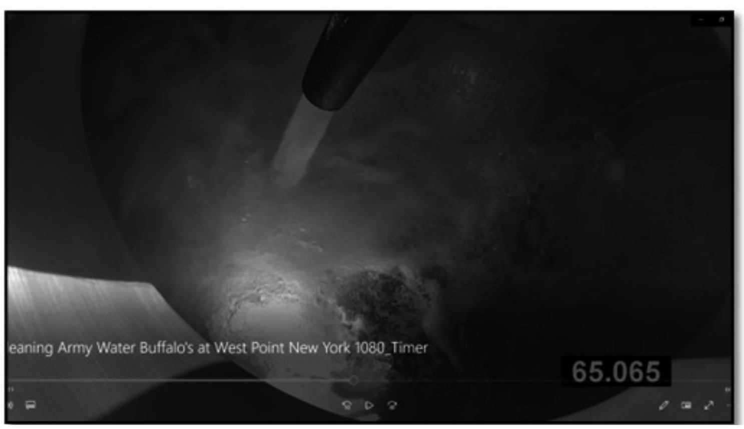


Figure 30 – ½ Full (T=65.0)

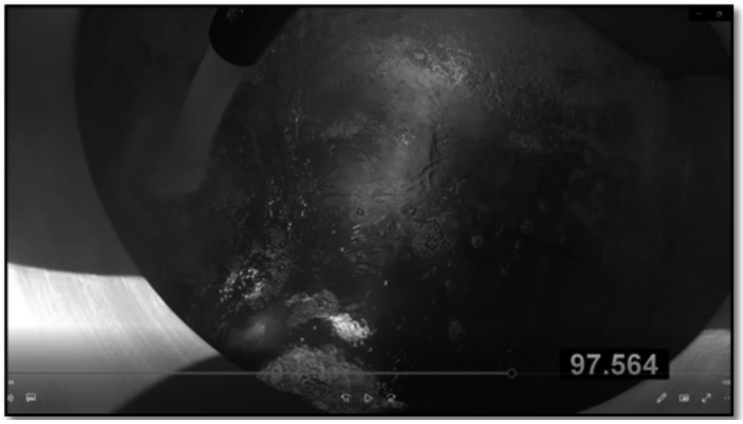


Figure 31 – ¾ Full (T=97.5)

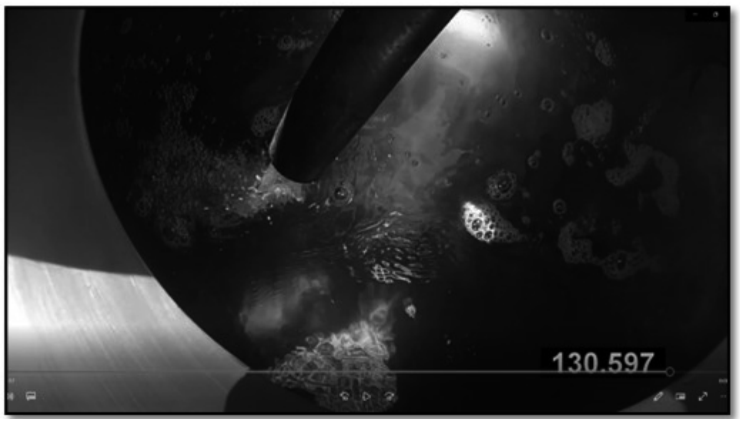


Figure 32 – Full (T=130.0)

As stated above, the fill time for a water source that provides a flow rate of 200 gpm was 2 minutes. The fill time is the ratio of volume (400 gallons) divided by flow (gallons per minute of the source). The chart below shows fill time would be for a 400 gallon at several source rates (Figure 33).

| Source GPM | Fill Time (minutes) |
|---|---|
| 100 | 4.0 |
| 150 | 2.7 |
| 200 | 2.0 |
| 250 | 1.6 |
| 300 | 1.3 |

Figure 33 – Tank fill times

Based upon distribution system testing performed by ATSDR in 2004, we have data that provide pressure and flow rates for the HPWTP. The graph below is from “Field Testing of Water-Distribution Systems at U.S. Marine Corps Base, Camp Lejeune, North Carolina, in Support of an Epidemiologic Study”. It provides system pressures at two different locations in the HPWTP system (Figure 34). These pressures combined with a 2 inch standpipe system are consistent with a 200 gpm flow rate.

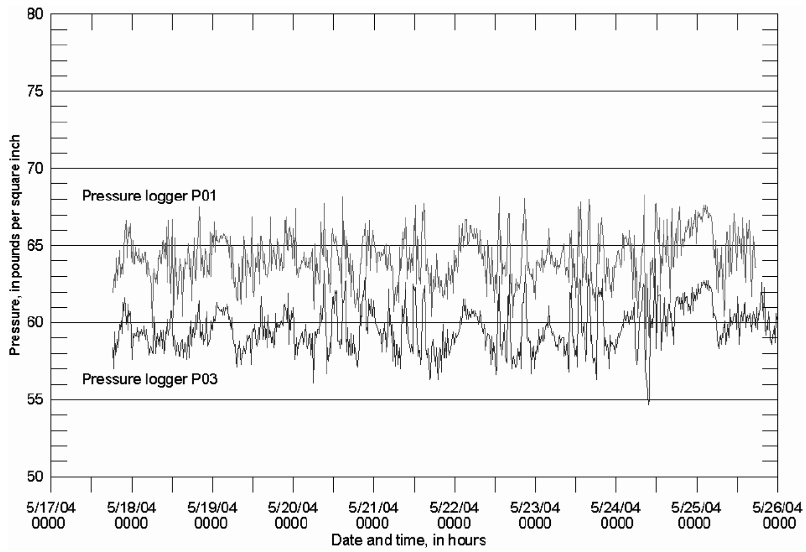


**Figure 5. Graphs showing recorded pressure data in the Hadnot Point WTP area, May18–25, 2004 (refer to Figure 3 for hydrant locations)**

Figure 34 – HPWTP Area Pressures (CLJ134936-CLJ134949)

The table below is from the same document. It provides flow rates at various locations in the HPWTP (Figure 37). These data confirm that HP WTP had more than enough capacity to fill the water buffaloes in the 2-to-3-minute range.

**Table 3. Hazen-Williams C-factor Values for Holcomb Boulevard and Hadnot Point Water Treatment Plant Service Areas, August 2004**

| Test ID | Pipe Length, ft (m) | Nominal Diameter, in. | Flow, gpm | Pipe Material | Computed C-factor | Reference C-factor* |
|---|---|---|---|---|---|---|
| CF-H01 | 848 | 12 | 1,603 | PVC | 161 | 147 |
| CF-H02 | 1,181 | 8 | 590 | Cast iron | 102 | 97–102 |
| CF-H03 | 793 | 6 | 564 | Cast iron | 93 | 97–102 |
| CF-H04 | 1,558 | 8 | 715 | Cast iron | 122 | 97–102 |
| CF-H05 | 700 | 10 | 947 | Cast iron | 77 | 97–102 |
| CF-H06 | 1,416 | 10 | 835 | PVC | 113 | 147 |
| CF-H07 | 1,167 | 8 | 835 | Cast iron | 117 | 97–102 |
| CF-H08 | 1,672 | 10 | 920 | Asbestos cement | 148 | 150 |

*Data from Walski et al. (2003)
1 in. = 2.52 cm; 1 ft = 0.3048 m; 1 gpm = 0.6309 L/s

Figure 37 – HPWTP Area Flow Rates (CLJ134936-CLJ134949)

**Summary**

Based upon my review of Dr. Hennet's and Dr. Brigham's expert reports, my review of documents produced in this litigation, and my research into the history and evolution of the water buffalo, I have reached the following opinions and conclusions:

1. From August 1972 forward the water buffaloes at Camp Lejeune, which would include the M107 (all types) and M149A1 & A2, were to be filled through the manhole cover.
2. Prior to August 1972, for filling convenience it is more likely than not that the water buffaloes at Camp Lejeune were filled through the manhole cover.
3. The M149A1 & A2 were not equipped with a filler neck, and the manhole cover was the only way to fill the tank.
4. The typical fill time for all 400-gallon tank water buffalos was more likely than not between 2 and 3 minutes when filled through the manhole cover using water supplied from a 2-inch standpipe directly tapped into a typical water distribution system.

Prepared by:

**David Sabatini, PhD, PE, BCEE**
January 14, 2024

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Figure 11 - Photographs, M149A1, https://www.bigiron.com/Lots/1968Army400-Gal2-WheelM149TankTrailer. Last accessed January 14, 2025.

Figure 24 - Photographs, Tank Filling, https://www.alamy.com/a-service-members-at-fort-mccoy-wis-for-the-86th-training-divisions-combat-support-training-exercise-cstx-86-18-02-fills-a-water-tank-at-improved-tactical-training-base-liberty-on-north-post-on-aug-8-

2018-the-86th-is-holding-the-exercise-as-part-of-the-us-army-reserve-commanding-generals-combat-support-training-program-thousands-of-service-members-with-the-army-as-well-as-other-military-services-and-foreign-militaries-are-participating-in-the-multinational-exercise-including-canadian-armed-forces-members-cstx-86-18-02-is-the-second-of-two-cstxs-by-the-86th-taking-place-at-fort-m-image218541597.html?imageid=7D23ADD4-DE29-445D-A5B2-5F209B22D886&p=725760&pn=1&searchId=0552ab94b97dc8d1ff6efee3a2cf3201&searchtype=0. Last accessed January 14, 2025.

Figure 25 - Photographs, Tank Filling, https://www.usmilitariaforum.com/forums/uploads/monthly_2024_09/Screenshot2024-09-23at21-01-23WaterWorks.png.a78205954b395f11a15d1e0aadbc071e.png. Last accessed January 14, 2025.

Figure 26 - Photographs, Tank Filling, https://itoldya420.getarchive.net/amp/media/us-marine-corps-lance-cpl-codi-heggemeier-2nd-medical-d523c0. Last accessed January 14, 2025.

Figure 27 - Photographs, Tank Filling, https://www.nationalguard.mil/Resources/Image-Gallery/News-Images/igphoto/2000709524/. Last accessed January 14, 2025.

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